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ABSTRACT

A group of scientists and science educators has developed and pilot tested an integrated physical science program designed for preservice elementary school teachers. This document includes the syllabus and class materials for the Physics block of the physical science courses developed by the group. Included are diagrams, lecture notes, homework problems, laboratory exercises and evaluation materials to be used with the course. Topics include: (1) measurement; (2) motion; (3) Newton's Laws; (4) dynamics; (5) the nature of force; (6) work and energy; (7) gas laws and heat transfer; (8) electricity; (9) electrical circuits; (10) electromagnetism; (11) magnets and motors; (12) reflection and refraction; (13) interference; (14) electrons and atoms; (15) lenses; and (16) radioactivity. (CW)

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PHYSICS LECTURES AND LABORATORIES

A MODEL TO IMPROVE PRESERVICE ELEMENTARY SCIENCE TEACHER DEVELOPMENT

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FINAL REPORT

Submitted to the National Science Foundation

A MODEL TO IMPROVE PRESERVICE ELEMENTARY SCIENCE TEACHER DEVELOPMENT

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PHYSICS LECTURES AND LABORATORIES

A MODEL TO IMPROVE PRESERVICE ELEMENTARY SCIENCE TEACHER DEVELOPMENT

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NSF Grant No. TEI-8470609
Volume II

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
ASTR 300 -- PHYSICS BLOCK
Spring 1987

INSTRUCTOR: M.J. Dresser	Office: Ph.S. 527
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Text: "Physics in Your World,"
Author: K. F. Kuhn & J. S. Faughn (K&F)

Date	Lecture	Topic	Supplementary Reading in K&F
Mar. 16	1	Measurement	7-15
18	2	Motion	16-17,34-38
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20	3	Vectors	21-31
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May 1	20	Radioactivity	465-495
7		FINAL EXAM 8:00 AM	

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

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GENERAL INTRODUCTION: From the earliest age that a child can communicate, their curiosity about nature and its behavior is evident. The questions of "why?" which sometimes exhaust the patience of the adults around them, are many times the same questions that have driven scientists to explore the mysteries of nature. Those explorations have resulted in a clearer view of nature, but as each mystery is explored and becomes less mysterious, new mysteries become evident that arouse the inherent curiosity of people to study them. We have found that the unravelling of mysteries has in most cases been to our benefit because as we develop understanding, we can better employ nature to our benefit. Machines do work we cannot, medicines cure the previously uncurable, and new materials are found that adapt to our requirements where others failed. Transportation and communications have taken us from a world of isolated families, communities, and tribes to a massive interrelated world society which on one hand seems exciting and filled with potential but on the other hand is frightening in its complexity and variety. Thus while science has given us many benefits it has also created some of our most complex problems. Living in these times then requires that we have a populace that is generally at ease with and somewhat conversant in the sciences. Just as the knowledge from science has contributed, in part, to our problems so must an understanding of science be involved in the solution of those problems.

To that end we will try to create a course that involves specialist teachers who demonstrate both the process and substance of physical science in a manner that is intriguing and stimulating to the potential elementary teacher. We feel that the ability of an elementary teacher to feel at ease while presenting physical science topics or encouraging their students in those studies is critical to the improvement of attitudes toward the physical sciences found in our general society.

Using specialist teachers in the physical sciences requires that we use subject matter breakdowns that are evident at the University level but rather meaningless at the elementary level. The four blocks of this course will be Physics, Chemistry, Geology, and Astronomy. All of these topics become blended as they are implemented into elementary educational programs so that the elementary teacher must be able to draw on knowledge from several academic areas for a single classroom topic. The primary goal of this course is then to provide the future teacher with sufficient knowledge of the subject matter in the Physical Sciences that they can feel confident when called on, to present these topics to the elementary class. It is assumed that these students will be concurrently enrolled in a science methods course which parallels this and deals with the implementation of the topics of this course in an elementary situation.

PHYSICS INTRODUCTION: The domain of physics includes the search for some of the most fundamental of the laws which govern the behavior of matter and how these laws combine to explain the phenomena of nature that we observe. Topics in Physics include motion, force, energy, fluid behavior both at rest and in motion, temperature, electricity, magnetism, light and optics, and the construction of matter from the level of subnuclear particles through the construction of the atom to the nature of solids and fluids as an assembly of atomic particles. Our intent is to activate the childlike curiosity that pervades us all, to see that simple models and simple explanations infact explain far more of nature around us than might seem possible at first glance. Simple models are many times numerical in nature so that the quantification of phenomena and substances becomes an important part of this subject. The first step in quantification of physical phenomenon is to establish an appropriate measure. An understanding of measurement is crucial to the development of the physical sciences and particularly to the development of those topics in the domain of Physics. Thus we begin with the process of measurement and proceed to the topics of mechanics, (motion, force, and energy). We will then study the subject of heat and temperature followed by the topics of electricity and magnetism, and optics and light. Our final focus will be on atomic and nuclear construction and the use of physical models to aid our understanding of phenomena at that level.

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #1

I. Introduction

- A. Course Procedures and Plans
- B. Nature of Physics
- C. Measurements
    - 1. process (comparison)
    - 2. definitions (conventions)

length } Show examples
time
mass

II. Kinematics

- A. Speed (Demo Air Track horizontal or tipped)
    - 1. average
    - 2. instantaneous
    - 3. examples
- B. Acceleration - deceleration
    - 1. average
    - 2. instantaneous
    - 3. examples

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #2

I. Review of Kinematics

  A. Position

  B. Velocity

II. Kinematics (cont.)

  B. Acceleration - deceleration

    1. average

    2. instantaneous

    3. examples

  C. Description of Motion

    1. constant acceleration

    2. useful formulae

$x - x_o = at^2 + v_o t$ (Ball down sloped hill)

$v^2 - v_o^2 = 2a(x - x_o)$

    3. examples

freefall experiments (Feather & Farthing)
  g = const. for everything
    (ignoring air drag)

Talk about describing a ball's motion when tossed up (or down) ± velocity, ± acceleration, ± position

    4. numerical examples

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #3

I. Review of Kinematics

- A. Position
- B. Velocity
- C. Acceleration
- D. Formulae for const. acceleration

$$x - x_o = v_o t + \quad at^2$$
$$v^2 - v_o^2 = 2a(x - x_o)$$

Watch signs!

II. Kinematics in 2 or 3 dimensions

- A. Vectors
    - 1. magnitude & direction
    - 2. position vectors
    - 3. velocity vectors

  coordinate arrows

- B. Combining vectors
    - 1. graphical addition
    - 2. components
    - 3. component addition

  ruler
  protractor

    - 4. subtraction (the minus vector)
- C. 2 dimensional motion
    - 1. independence of components
        - a. monkey hunter demo
        - b. other demos

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #4

I. Review of Examples

II. Dynamics - Answers the question

"Why do velocities change?" - or
"How can we change a velocity?"

A. The answer is - Force

A crude definition of force -
"That which changes velocity."

Newton said....(First law) - an object remains at rest or at constant velocity unless acted on by a net Force.

B. How do we measure force?

1. note dependence on mass

2. note dependence on acceleration

C. Action - Reaction

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #5

I. Review of concepts of force

II. Newtons laws of motion

  A. First---"rest or constant velocity"

  B. Second---"net force = ma"

  C. Third---"action-reaction"

III. Application examples of the three laws

  A. Ball with string above and below

  B. Tablecloth from under a place setting

  C. Tractor and log

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #6

I. Review of Newton´s Laws

A. 1st Law (defines Force as that which changes velocity)

2nd Law - quantifies Force via $F_{net} = ma$
3rd Law - Action-Reaction...Forces come in pairs

B. Applications

1. Units of Force

$kg(m/s^2)$ = Newton = N, English Pound is force of g

$$F = mg$$

$$m = f/g = lb/(ft/s^2) = \text{Slug}$$

2. Weight vs Mass

Weight is force of g on matter, Mass is quantity of matter

if $F_{net} = mg$

$$m = F_{net}/g = w/g$$

II. Momentum

Defined as $P = mv$

Since
$$F_{net} = ma = m\frac{(v - v_o)}{t}$$
$$= \frac{mv - mv_o}{t} = \frac{P - P_o}{t}$$
$$= \frac{P}{t}$$

or $P = F\ t$ -- $F\ \ t$ is called impulse

Bat hits ball with F for t -- Changes momentum by P

if $F = \ P/\ t$

and if $F = 0$

$P = 0 \Rightarrow P$ = constant conservation of momentum

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK --- LECTURE #7

I. Review of Newtons laws.

II. Another Application - person on an elevator

$a = 2\ m/s^2$, $m = 100$ kg, find the apparent weight.

III. Work

- A. No work if no change in position
- B. No work if force is perpendicular to the motion
- C. Work is negative if motion is opposite to force

IV. Potential Energy (mgy for gravity)

- A. Energy of position
  - 1. Work to put it there
  - 2. Work it can deliver if released

V. Kinetic Energy (mv+2 /2)

- A. Energy of motion
  - 1. $F_{net} = ma$ from Newton II
  - 2. $v^2 - v_o^2 = 2\ ax$ Kinematic #4
  - 3. $W = F_{net}\ x = (ma)\ x = m\ (ax)$
    $= m(v^2 - v_o^2)/2$
    $= KE - KE_o$
  - 4. This is called the work energy theorem: Work by a net force is equal to the change in the kinetic energy.

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #8

I. Review of work and energy

- A. Work ($F \quad x$)
- B. Potential Energy (mgy for gravity)
- C. Kinetic Energy ($mv^2/2$)

II. Conservation of energy

- A. Hills and valleys
- B. Loop the loop

III. Circular motion

- A. Centripetal vs. centrifugal
- B. Centripetal force (mv^2/r)
- C. Torque and rotational acceleration ($T = Ia/r$)
- D. Moment of inertia ($I = \{\text{number}\}mr^2$)
- E. Angular momentum and conservation ($L = Iv/r$)
- F. Rotational kinetic energy ($KE_{rot} = I(v/r)^2/2$).

IV. Conservation of total energy

$$TE = PE + KE_{tran} + KE_{rot}$$

tran. is motion of center and rot. is rotation about the center. Tran. is translation.

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #9

- I. Review of rotational motion
    - A. Torque ($T = F\ r_{perp}$)
    - B. Angular dynamics ($T = I\ a/r$)
    - C. Angular momentum ($L = I\ v/r$)
- II. Wrap up of rotational motion
    - A. Angular energy ($KE_{rot} = I\ (v/r)^2/2$)
    - B. Conservation of all energy
- III. Temperature and heat
    - A. Temperature and thermometric properties
    - B. Linear expansion
    - C. Heat capacity

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #10

I. Review of rotation and temperature

  A. Rotation conservation of energy in translation and rotation

  B. Temperatures

  C. Thermometric properties -- Pressure

II. Heat as a form of energy

  A. Heat capacity of materials

  B. Heat transfer

    1. conduction

    2. convection

    3. radiation

  C. Phase changes

    1. boiling point, freezing point

    2. Triple point

    3. latent heat of transformation

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #11

I. Review of heat concepts
   A. Temperature
   B. Heat and heat capacity

II. Heat Transfer
   A. Conduction vs Convection
   B. Radiation

III. Boiling and Melting
   A. The melting point (Fusion)
   B. The boiling point (Condensation)
   C. Heats of transformation
   D. The Triple point

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #12

I. Review of Exam

II. Static Charge

  A. Strong Force

  B. Two Kinds (+,- The Franklin convention)

  C. Force Fields

  D. Charging by induction

III. The Electric Field

  A. Point charge

  B. Parallel Plates

  C. Other shapes

  D. In and around conductors

IV. Charge Storage (Capacitors)

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #13

I. Review of Electric Fields
  A. Charges
  B. Fields around shapes
II. Charging objects
  A. Induction
  B. Storage
III. Potential (Energy / charge)
  A. Work against the field
  B. Moving charge
  C. Ohms Law
  D. Series and Parallel

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #14

I. Review of potential and current

II. Current (the ampere = coulomb per second)

III. Resistance

  A. Ohms law

  B. Resistance units

  C. Parameters of resistance (The salt tube)

IV. Circuits

  A. Symbols

  B. Sources of potential

  C. Series

  D. Parallel

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #15

I. Schedule makeup for Friday

II. Review of currents

III. Circuits

  A. Symbols

  B. Series

  C. Parallel

IV. Magnetic fields

  A. Poles

  B. Materials

  C. Magnetization

V. Magnetic forces on moving charges

  A. Bending an electron beam

  B. Jumping wire

  C. Meters and motors

VI. Magnetic fields of currents

  A. A wire

  B. Coils

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #16

I. Review of Magnetism

II. Magnetic forces on moving charges

  A. Bending an electron beam

  B. Meters and motors

III. Magnetic fields of currents

  A. A wire

  B. Coils

  C. Electromagnets

  D. Atomic electron currents a source of magnetism

IV. Magnetically induced electric fields

  A. Moving wire

  B. Moving coil

  C. Moving Field and Lenzes law

  D. Transformer and AC

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #17

I. Review of Electricity and Magnetism

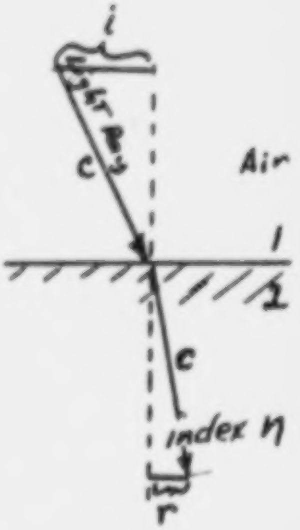
II. Light (Electromagnetic waves)

  A. Speed in vacuum 3×10^8m/s for all observers!

  B. Reflection and construction of images

  C. Refraction, Snells law.... $i = nr$ (See figure to the right)

  D. Speed of light in materials - index of refraction



III. Refraction of objects

  A. Parallel surfaces

  B. Prisms

  C. Curved surfaces - lenses

  D. Focal point

  E. Ray tracing - images

  F. $1/f = (1/I) + (1/0)$

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #18

I. Review of Refraction
  A. Lenses
  B. Focal point

II. Image construction
  A. Ray tracing
  B. $1/f = (1/I) + (1/O)$

III. Light as a wave
  A. Interference from separate sources
  B. Diffraction from a single source
  C. Gratings

IV. Polarization

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #19

I. Review of Interference

II. Diffraction from gratings
  A. Interference from adjacent slits
  B. Light sources
  C. Spectra

III. Atomic models
  A. Electrons
  B. Orbits vs. standing waves
  C. The nucleus

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- LECTURE #20

I. Review of the atom

II. Standing waves of electrons

A. Bohrs criterion $n\lambda$ = Circumference of orbit $\lambda = v/f$, λ is wave length, v is wave velocity and f is frequency or $f = 1/T$ where T is time for one cycle.

B. De Broglie´s hypothesis $\lambda = h/mv$, the particle wave connection. $h = 6.6 \times 10^{-34}$ joule sec

C. Plancks Quantum $E = hf$. This is the energy carried by one light particle or a photon.

III. The nucleus

A. Nucleons --- Protons and neutrons

B. Nuclear size and stability

C. Alpha, beta, and gamma decay

D. Fission and Fusion

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

CHAPTER 1 -- MEASUREMENTS

If one seeks to begin at the very beginning of a subject one finds that most fundamental of definitions are the most difficult, not because of their complexity but because of their simplicity. They seem so obvious that we struggle with finding a precise statement that covers the full character of this simple concept. Position and time are two such entities in the subject of Physics, and we choose to define them not in a verbal statement but rather in the process of how they can be measured. If we all agree on how something is to be measured then we will all be talking about the same property when we compare our results. There can be no ambiguity. That is not to say that our preconceptions of the nature of this property may not differ from that of others but we are at least in agreement that the measurements are identical.

A specific example will be of more help than further generalities so let us consider what position means. The pertinent dictionary definition from Webster's "New Universal Dictionary" 2nd Ed. states,

> "The place occupied by a person or thing; site; situation; location; as, the position of a building; the position of a figure in a picture".

However if one looks up the definitions of "place, site, situation, or location" these definitions are defined in terms of the others. The definition becomes circular so this is not productive. We then take the other course; we base our definition on the understanding of how we are going to measure the position. To measure position we need (A) a frame of reference and B) a unit of measure. The process of determining the position of an object will be to measure the number of units that that object lies from the origin of our agreed upon frame of reference. We will also have to agree on how we handle different directions and which point within the object we are using to determine location, but these are refinements we will discuss later, so let us proceed assuming that they can be resolved. Say we have agreed that a particular stick is to be our unit of length and so we lay down the stick with one end on the origin and direct the other end toward the object we are trying to locate, see Fig. 1.

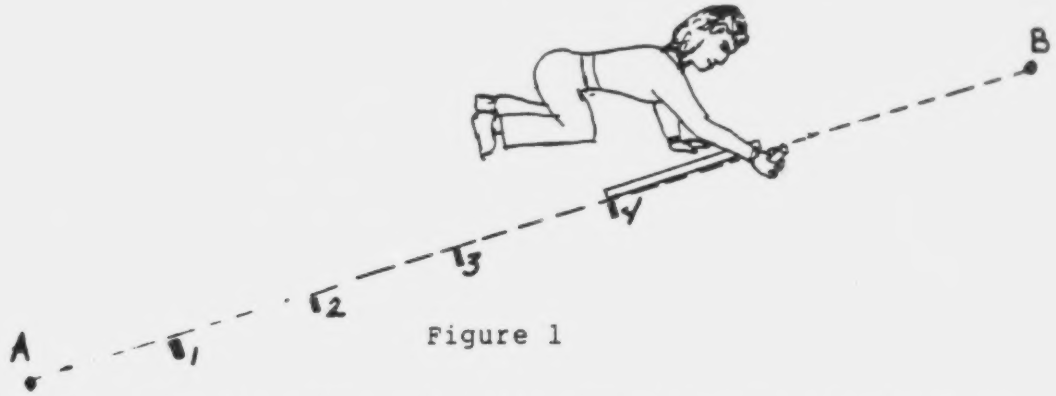


Figure 1

We mark where the other end falls and then move the stick so that one lies on that mark and the other end is directed toward our object of interest. For the moment assume that the object is several lengths away from the origin. We mark the location of the end nearest the object and repeat the process until we arrive at the object. If we count the number of lengths thus required we say that that is the distance measured (at least crudely). It is crude because we rarely come out with an exact number of lengths and we have to determine how to measure fractional lengths. This is done by finding a shorter length that is an exact fraction of the agreed upon unit length, for example say we find a stick that is exactly 1/10 of our unit length. We can of course test it by measuring the length of the unit length with the short stick and it will be exactly 10 short lengths long. Now we return to our original task of finding the position of an object. If the object lay beyond the 14th length but closer than the 15th, we get our short length unit out and find out that the object was beyond the 6th short length but closer than the 7th short length, then our position is 14 lengths plus 6 or 7 short lengths (whichever is closer, say 6), so the distance is 14.6 lengths. We are uncertain of our length to one short length and if we desire more accuracy in our position we must find a shorter length to subdivide the remainder with. We continue that process until our accuracy is sufficient for the job. This is of course a ridiculously painful process and we quickly learn that measurement is easier if we print the necessary subdivisions on our stick so we can call it a ruler.

The time measurement process is done similarly but first requires a comparison unit for time. People have observed over the centuries that a pendulum swings with a very regular frequency. We shall call the time for one round trip a "Period". Thus the period of a given pendulum can become the basis of our time measurements. For example if we want to know the time between the start of class and the end of class we count the number of swings of the pendulum and that is the number of our units of time in the interval. Since there will probably be some fraction of a swing left over, the error in our count is at most the time of one swing (a period). If we desire more accuracy we find a standard that oscillates faster so that the period is shorter.

The units of mass are defined by comparison to a reference chunk of material. If we have many identical chunks the mass of unknown materials can be compared in balance pans to the number of chunks it takes to balance. We will come back to the idea of mass later on and be more thorough in our description of that concept.

We should by this point have a good visualization of the measurement process for distance (or position) and time, so we next turn to the common units of length or time that are used. There are several possible sets of agreed upon units of which two are most common in the USA. These are the Systeme´ International (metric) and the English system. While the English system is the most commonly used system in the USA for everyday transactions, the pressures of world trade are driving us to conversion to the metric system. At present we are the only nation not committed to that conversion process. Thus preparing youth for the future requires that we provide them with a familiarity to the worlds system of units as well as some knowledge of our english units. This course will use the metric units exclusively with the exception that occasional references to english units in text examples may occur to give the student a sense of size in units that are most familiar to them.

The Systeme´ International, (or SI as it will be referred to from here on) has its fundamental unit of length the meter. The meter is just slightly longer than one yard (39.37 inches) and for rough comparisons we may think of them interchangeably. The great advantage of the metric system is the way in which units are divided or multiplied. A set of prefixes is defined so that the same prefix is used for all units. See Table 1.

Table 1. The Metric Prefixes

Name	Symbol	Decimal Value	Exp.
Tera	T	1,000,000,000,000.	10^{12}
Giga	G	1,000,000,000.	10^{9}
Mega	M	1,000,000.	10^{6}
Kilo	K	1,000.	10^{3}
(unit)		1.	10^{0}
[centi	c	0.01	10^{-2}]
milli	m	0.001	10^{-3}
micro	(mu)	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}
femto	f	0.000 000 000 000 001	10^{-15}

The centi unit is bracketed because its use is almost entirely in conjunction with meter as in centimeter or occasionally as centigram. Powers of 1000 have become much more popular and are the only ones we will use in this course. There are also a few prefixes not shown here that are commonly presented when metric units are presented but, because those prefixes are rarely used, they are omitted from this table. These unlisted prefixes correspond to multipliers and dividers of 10 and 100.

Thus the prefixes give us a set of multipliers which provide us with subunits and multiple units which always go by powers of ten and usually go by the factor of 1000. Contrast this with the task of remembering the number of inches in a foot, feet in a mile, or seconds in an hour, you only remember 1000, (instead of 12, 5,280, or 2600), since there are 1000 millimeters in a meter, 1000 meters in a kilometer and 1000 secs in a kilosecond.

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS SECTION

CHAPTER 2 -- MOTION

VELOCITY

With our concepts of length and time we can now begin to describe motion in more detail. We begin by discussing velocity. Velocity is a rate, a rate of change of distance with time. You may remember equations like distance = rate x time or the rate = distance/time. We call this rate average velocity and express the above equation in a new form,

$$v_{ave} = x - x_o/t,$$

or the average velocity of an object is found by dividing the change in position of that object by the time it took to make that change. The units of velocity will be m/s or miles/hour or some other distance unit divided by some time unit. In this definition we do not worry about the details of what actually happened between the two end points, only the net change in position divided by the corresponding time. For example a student notes that she travels 1/4 mile on her bicycle in 1 minute, thus her average velocity is (1/4 mile) / (1 minute) = .25 mile/min. Many times we would prefer to know that result in miles/hour. Since there are 60 min in 1 hour we multiply the previous result by (60 min/hour) and get (.25 mile/min) * (60 min/hour) = 15 mile/hour. A metric example of the same calculation is given by; "A hiker notes that they have traversed 250 m in a time of 6 min. What is the hikers average velocity." For this problem $x - x_o$ = 250 m and t = 4 min or 240 s, thus the average velocity is (250 m) / (240 s) = 1.04 m/s. Thus the hiker averages 1.04 m/s even though they may have jogged part of the distance and sat down for a rest at some other time in the 4 minute interval.

In class we will measure the change in position of a glider on the air track and the corresponding change in time for a 1 m interval. From that measurement we will then calculate the average velocity in the interval. We can then shrink the interval down to .5 m and repeat the experiment finding a time that is about half of the previous time so that when we calculate the average velocity we will get essentially the same value as before. Although we won't have time to reduce the interval further we can note that further reduction will always give the same average velocity because the time always decreases by the same amount as the distance so that their ratio is constant.

Instantaneous velocity is then defined as the value we get after reducing the interval as far as conceivable. This became particularly useful when we go to a tilted air track where the glider is changing velocity continuously as it speeds up going down the track. We can therefore measure the velocity at any point on the hill by shrinking the interval around the point in question and then taking the ratio of Δx / Δt until the ratio is not affected by the size of the interval. This is primarily a conceptual process and we will not normally do this but it is important in our understanding of what is meant by instantaneous velocity.

ACCELERATION

After noting the changing velocity of the glider in the previous discussion we recognize the need to quantify how that velocity is changing. We begin in close analogy to the previous discussion by defining the average acceleration as a rate, a rate of change of velocity with time or;

$$a_{ave} = (v - v_o) / t.$$

Or average acceleration is the change in velocity divided by the corresponding change in time. The units of acceleration are (m / s)/ s which by the rules of division of fractions can be written; $(m / s) * (1 / s) = m /s^2$ or sometimes strange mixtures of time units like (miles/hour)/ s. We must be careful here. Note that in earlier math classes your equations for rates always assume the rate is constant. Thus if velocity, a rate, changes (i.e., accelerates) the simple equation distance = rate ˙ time does not work. We will come to the correct procedure for this case a little later.

Of course we can extend this definition to instantaneous acceleration as we did for instantaneous velocity. If we shrink the interval of time in which the measurement of Δv is made the ratio $\Delta v / \Delta t$ becomes constant and independent of the interval size. This is the instantaneous acceleration at the center of the interval. For many situations the acceleration does not change much and we can deal with one special case, that is the case of constant acceleration.

In the case of constant acceleration the instantaneous value of acceleration is the same everywhere so that the average acceleration is equal to the instantaneous acceleration everywhere. In this case then;

$$a = (v - v_o) / t,$$

or;

$$v = v_o + at. \qquad [\ 1\ ]$$

We will subsequentally refer to these equations as the definition of acceleration. We also note that if the acceleration is constant then,

$$v_{ave} = (v + v_o) / 2,$$

so that the definition of average velocity gives us;

$$v_{ave} = (x - x_o) / t = (v + v_o) / 2$$

or;

$$x - x_o = (v + v_o)\, t / 2. \qquad [\ 2\ ]$$

We refer to either form of the above equations as the definition of velocity equations. There are two other equations that we will use for convenience although all problems can be solved with the two equations above. The first of these other expressions is;

$$x - x_o = (1/2)\, at^2 + v_o t, \qquad [\ 3\ ]$$

which relates x,a,t. The second additional expression is;

$$v^2 - v_o^{\,2} = 2\, ax, \qquad [\ 4\ ]$$

which relates x,v,a. Thus with these equations for constant acceleration we can describe or predict all the details of that motion. Note that each equation relates three of the four variables x,v,a, and t. Equation [1] relates v,a,t, equation [2] relates x,v,t, equation [3] relates x,a,t, and equation [4] relates x,v,a. When solving a particular problem take note of the variables you are given or asked to find and then which of these expressions is most useful will become apparent.

The most common case of constant acceleration is that of the acceleration of gravity on earth. We find that all objects when allowed to fall freely (i.e. no friction or air drag) fall with the constant acceleration of $9.8 m/s^2$. For most cases we will call this $10 m/s^2$.

EXAMPLES

A. Motion from rest with positive acceleration --- find the position and velocity after time t.

> A car starts out from a stoplight with a constant acceleration of $2\ m/s^2$ (about 4.1 mph/s), how far has it traveled in 10 s? How fast is it going?

We first ask ourselves, what parameters do we know and what do we want to find? Since the car starts out from the stoplight we know $v_o = 0$ m/s, it has an acceleration of 2 m/s^2, and we are trying to find out position, x, after 10 s. Thus, this is an x,a,t problem and we will employ Equation [3]. For convenience we choose $x_o = 0$ m. Thus Equation [3] becomes;

$$x = (1/2)at^2.$$

substituting the given values into this equation we get;

$$x = (1/2)(2\ m/s^2)(10\ s)^2,$$

or

$$x = 100 \text{ m} \quad \text{(about 300 ft)}.$$

To answer the second question we know a,t and want to find v so we have a v,a,t problem which suggests the use of Equation [1].

$$v = at \quad (\text{since } v_o = 0 \text{ m/s})$$

$$= (2 \text{ m/s}^2)(10 \text{ s})$$

$$= 20 \text{ m/s} \quad \text{(about 60 ft/s or 41 mph)}$$

B. Motion from rest with a negative acceleration --- find the position and velocity after time t.

> A fat cat drops his favorite dog from a second story window and hears the dog hit the ground 1 s later. How far is the window above the ground and what is the dogs speed as he strikes the ground?

Again we note that $v_o = 0$ m/s, and the acceleration for this case is that of gravity, i.e. $a = g = -9.8 \text{ m/s}^2$. For our purposes we will use $g = -10 \text{ m/s}^2$ because the rounded value is easier to use and is accurate enough for our purposes. To find the height of the window above the ground we note that we know the acceleration and the time (i.e. an x,a,t problem) so we will use Equation [3], or $x = (1/2)at^2$. Thus we have;

$$x = (1/2)(-10 \text{ m/s}^2)(1 \text{ s})^2$$

$$x = -5 \text{ m} \quad \text{(about -15 ft)}.$$

The negative sign tells us that the position is in the negative direction relative to the window. Since we chose positive as upward the dog hits the ground below the window. This is of course obvious to our experience but I am showing that the mathematics above is consistant with our common experience.

We are also asked to find the velocity at impact so now the problem has variables of v,a,t and we go to Equation [1].

$$v = (-10\ \mathrm{m/s^2})(1\ \mathrm{s})$$

$$= -10\ \mathrm{m/s} \quad \text{(about 30 ft/s or 21 mph)}$$

C. Motion with an initial velocity and positive acceleration --- find the distance traveled and the final velocity in time t.

> In the Indianapolis 500 all of the racing cars are traveling at 15 m/s (about 34 mph) as they approach the starter. When the lead car receives the go flag it accelerates for 16 s at a constant rate of 5 $\mathrm{m/s^2}$ (about 11 mph/s). How far has this car traveled from the start line? What is its velocity?

Thus we are given $a = 5\ \mathrm{m/s^2}$, $t = 16$ s and $v_o = 15$ m/s. Again we will say $x_o = 0$ m. Now Equation [3] is written;

$$x = (1/2)\ at^2 + v_ot,$$

$$x = (1/2)(5\ \mathrm{m/s^2})(16\ \mathrm{s})^2 + (15\ \mathrm{m/s})(16\ \mathrm{s}),$$

$$x = \quad 640\ \mathrm{m} \quad + \quad 240\ \mathrm{m},$$

$$x = 880\ \mathrm{m} \quad \text{(about 2,900 ft or .55 miles)}$$

To find the velocity we go to Equation [1] and get;

$$v = v_o + at,$$

$$v = 15\ \mathrm{m/s} + (5\ \mathrm{m/s^2})(16\ \mathrm{s})$$

$$v = 15\ \mathrm{m/s} + 80\ \mathrm{m/s}$$

$$v = 95\ \mathrm{m/s} \quad \text{(about 210 mph)}$$

D. Motion with an initial velocity and a negative acceleration --- find the distance and velocity after time t.

> An arrow is shot straight upward with an initial velocity of 12 m/s (about 40 ft/s). Find the position and velocity at the end of each of the first 4 s.

Remember that up is positive (+) so that $v_o = + 12$ m/s, and again we can choose $x_o = 0$ m. We have acceleration (g) and times given and are asked for position so that this is an x,a,t problem so we go to Equation [3];

$$x = (1/2)\ at^2 + v_o t$$

$$x = (1/2)(-10\ \text{m/s}^2)(t^2) + (+12\ \text{m/s})\ (t).$$

If we calculate x for t = 2 s as an example we get;

$$x = (1/2)(-10\ \text{m/s}^2)(4\ \text{s}^2) + (+12\ \text{m/s})(2\ \text{s})$$

$$x = \quad -20\ \text{m} \quad + \quad 24\ \text{m}$$

$$x = 4\ \text{m}.$$

Other values of x for different values of t are entered in Table 2. The velocities are also calculated by using Equation [1] or $v = 12\ \text{m/s} + (-10\ \text{m/s}^2)\ t$. As we look at Table 2 we see that the second column gives the distance an object falls under gravity for the specific times.

Table 2

t	$(1/2)at^2$	+	$v_o t$	=	x	v
(s)	(m)		(m)		(m)	(m/s)
0	0		0		0	+12
1	-5		12		7	+2
2	-20		24		4	-8
3	-45		36		-9	-32
4	-80		48		-32	-28

Column 3 gives how far the object would rise if there were no gravity. Column 4 is the sum of columns 2 & 3 and shows us that the arrow is rising in the first second but is falling by the second second. The velocities in column 5 show the velocity turning around between 1 and 2 s.

E. Other questions for case D.

(1) How high did it go?
(2) How long does it take to return to x = 0 m?
(3) What is the velocity of the arrow at x = 0 m?

1. We want to find x when v = 0 m/s (i.e. at the top of the path). We know v,a and want to find x so we will use Equation [4];

$$v^2 - v_o^2 = 2\ ax,$$

$$v = 0\ m/s,\ v_o = 12\ m/s,\ a = g = -10\ m/s^2$$

$$(0)^2 - (12\ m/s)^2 = 2(-10\ m/s^2)x$$

$$-144\ m^2/s^2 = -20\ m/s^2\ x$$

$$x = 7.2\ m$$

2. How long will it take for x to return to zero? The variables now are x,a,t so use Equation [3],

$$x = (1/2)\ at^2 + v_o t$$

$$0\ m = (1/2)(-10\ m/s^2)t^2 + (12\ m/s)t$$

$$(5\ m/s^2)t^2 = (12\ m/s)t$$

$$t = 12\ m/s\ /\ 5\ m/s^2$$

$$t = 2.4\ s$$

3. What is the velocity at $x = 0$ m?

Use; $v^2 - v_o^2 = 2\ ax$

at $x = 0$ m we see $v^2 - v_o^2 = 0\ m^2/s^2$,

or $v^2 = v_o^2$

$v = +$ or $- v_o$.

To make sense we suspect that v is $+v_o$ at $t = 0$ s and $-v_o$ at $t = 2.4$ s. We can remove any doubt, however, with Equation [1];

$$v = v_o + at$$

$$v = (12\ m/s) + (-10\ m/s^2)(2.4\ s)$$

$$v = 12\ m/s - 24\ m/s$$

$$v = -12\ m/s \text{ at } t = 2.4\ s.$$

CHAPTER 3 -- VECTORS AND 2 DIMENSIONAL MOTION

As we try to locate different objects around us it becomes evident that how far away it is is not adequate for that description. We need to know in what direction the object is as well as how far it is away. This need is satisfied by the concept of a VECTOR. A vector can be thought of as an arrow whose length is related to the size of the property being described and which points in the appropriate direction for that property. In the beginning example of locating objects around us an arrow would reach from us to each object so that its length was the distance of that object from us and the direction of the arrow is the direction in which the object is located.

VECTOR ADDITION

A student is trying to putt their golf ball into the hole, see Figure 3-1. The first shot goes off to the right of the hole so that a second shot is required to "sink" it. Measurements made determine that the hole lies due north of the original position and was eight feet

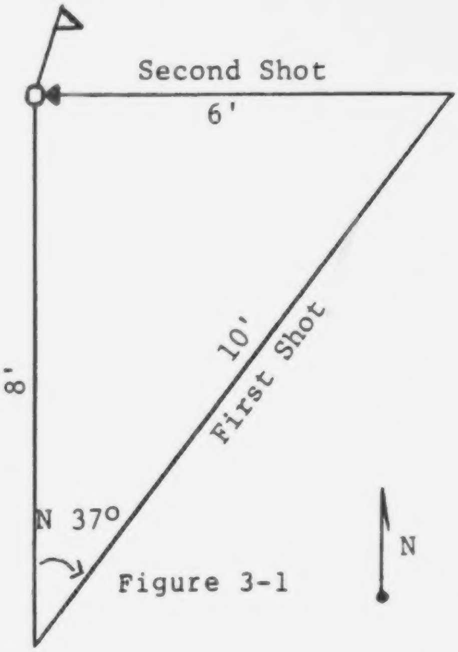


Figure 3-1

away. The players first shot was ten feet long and directed about 37° east of north. The new position of the ball is now six feet due east of the hole. This problem is best discussed in terms of vector sums. The players first shot can be represented by a vector that has a length of ten feet and a direction of 37° each of north. The players second shot should go due west six feet so that it is represented by an arrow of length six feet and a direction 90° west of north. The combination of these two arrows then represents the final position of the ball. A vector that connects the tail of the first to the heat of the last represents the single shot the player should have made, or in terms of vectors it is the vector sum of the other two vectors.

DEFINITION

The sum of two vectors can be found by placing the tail of the second on the head of the first. The sum is the vector that connects the tail of the first to the head of the second. Three or more vectors can be added by finding the sum of two of the vectors and adding that sum to a remaining vector until all the vectors are summed.

Note that while a vectors size and direction are crucial to its meaning, the position that it occupies is unimportant, so a vector can be moved to any position you desire, as long as its size and direction are not changed. In Figure 3-2 vectors A and B are to be added. Vector A is 3 units long (centimeters in our sketch) and points at 60° from the vertical. Vector B is 2 units long and nts at

135° from the vertical. In frame A we see the two vectors are separated from each other. In frame B we have shifted the vectors so that the tail of B is on the head of A.

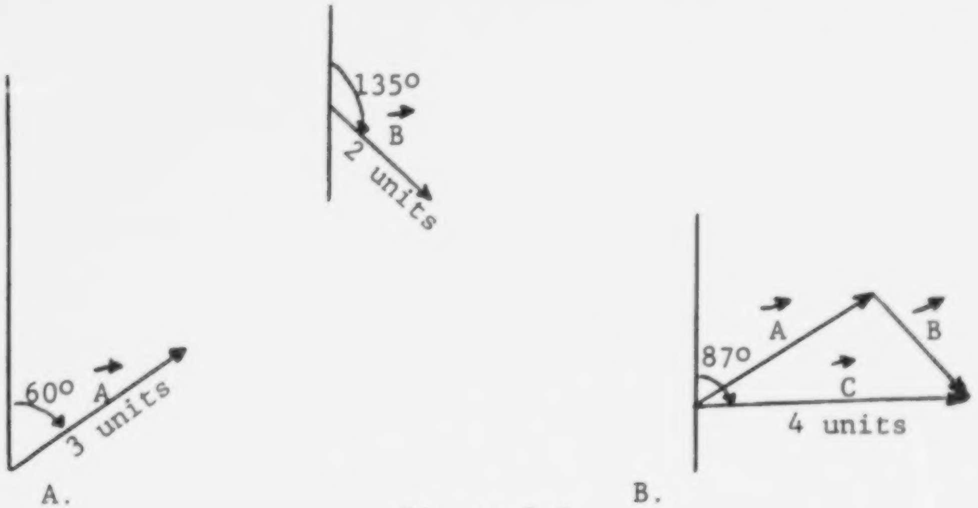
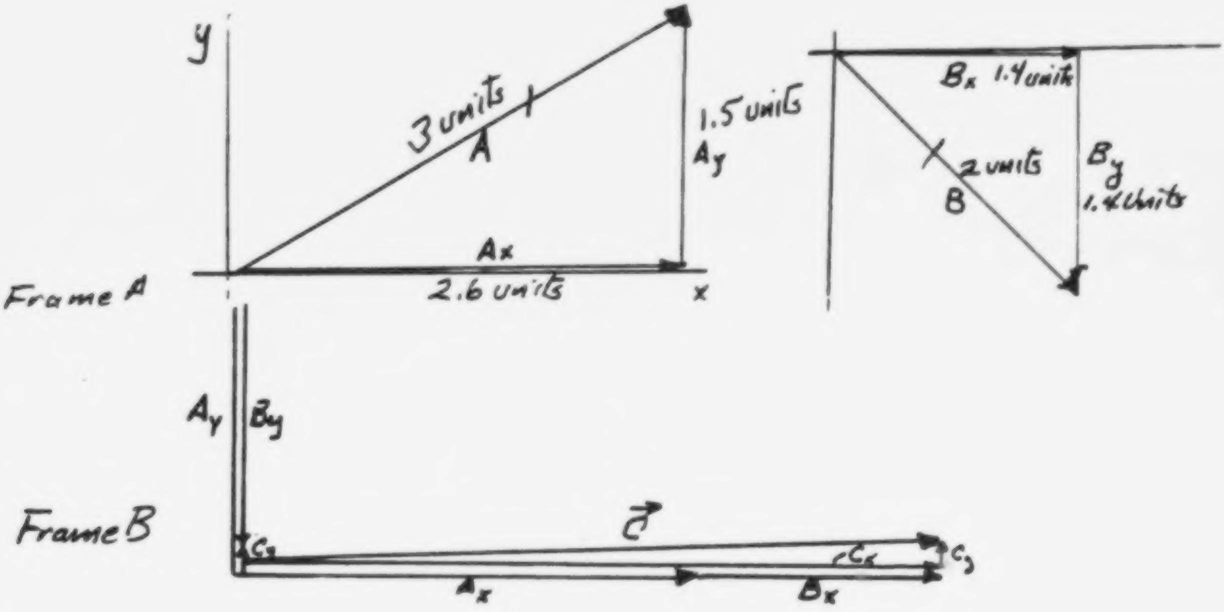


Figure 3-2

The vector C is the sum of A and B. With a ruler and protractor we measure the length of C and its direction. We find that C has a length of 4 units and a direction of 87° from the vertical. Thus the sum of (3,60°) and (2,135°) is (4,87°). You cannot determine this answer without going through the graphical process and measuring your answer (there are other mathematical ways of determining this answer but we will not introduce those methods in this class).

VECTOR COMPONENTS

We have seen how to add vectors so that a group of vectors can be replaced by a single vector whose effect is the same as the collective action of the group. This means that any vector could be thought of as the sum of some other vectors whose directions might be more convenient for our consideration. For example if we draw a set of axis (x,y) and draw vectors parallel to the x or y axis which sum to the given vector, we can then replace the given vector by these new vectors, which we call its components. In Figure 3-3 we show the vectors A and B of Fig. 3-2 and their respective (x,y) components. The components replace the original vector so we draw two short lines across the original vectors since they are no longer required.



y
3 units
A
1.5 units
A_y
Ax
2.6 units
x
Frame A
B_x 1.4 units
2 units
B
B_y
1.4 units
A_y
B_y
Frame B
$\vec{C}$
C_y
C_x
C_y
A_x
B_x

Figure 3-3

At first it may seem that we have made the problem more difficult because where we used to have 2 vectors we now have 4. But, 2 of the new vectors are parallel to the x axis and the other two vectors are parallel to the y axis so now adding the parallel vectors is like simple addition. The sum of the x components is the x component of the answer and the sum of the y components is the y component of the answer. In frame B of Fig. 3-3 we see the components combined to give us the vector sum, C, and note is the same result as we got in Fig. 3-2. This component method may not seem easier for vector addition, but its real usefulness comes in Physical situations where motions (and other vector quantities) are easier to visualize in components. Our next section is a good example of such a situation.

TWO DIMENSIONAL MOTION

In chapter two we discussed the case of an arrow being shot straight up into the air, we would now like to consider the case of the arrow shot at some angle above horizontal so that it traverses some distance as it goes up and down. The important concept in this discussion is the independence of motion in different directions. Several different classroom demonstrations were used to make this point. Figure 3-4

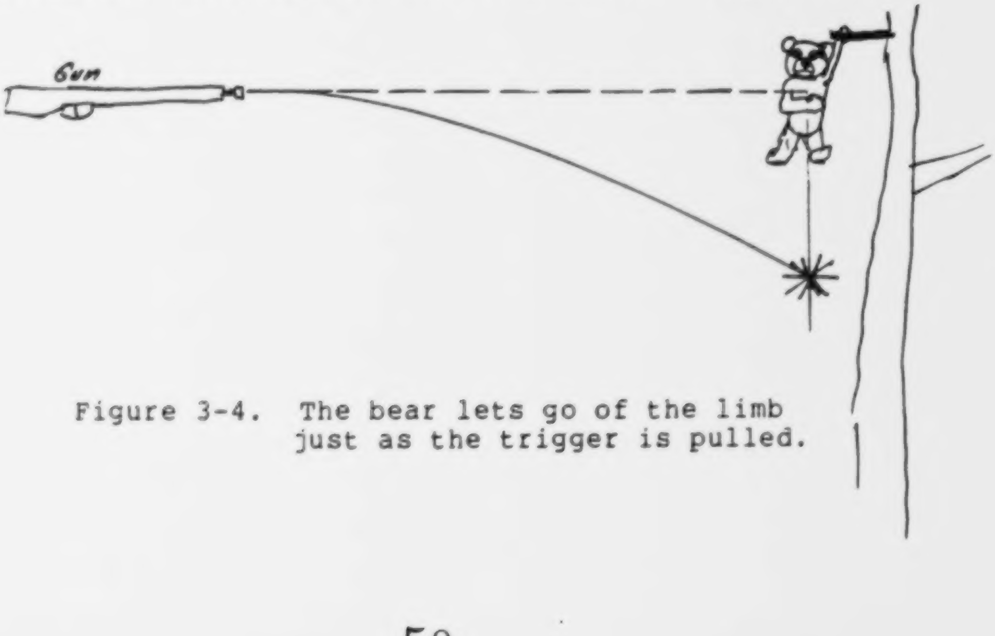


Figure 3-4. The bear lets go of the limb just as the trigger is pulled.

force is not zero then an acceleration will result. Note that an object sitting on the table is pulled by gravity downward and is being pushed upward by the surface of the table. Thus the object has two forces acting on it but they are equal and opposite so there is no net force and the object remains at rest. It is easy to imagine situations where an object is at rest but has many forces acting on it. If we remove any one of these forces the remaining forces cannot sum to zero so the object must begin to move. Thus any of the forces are capable of accelerating the object but only the net force will accelerate it.

NEWTON´S SECOND LAW

If a system experiences a net force it will respond to that force with an acceleration that is directly proportional to that net force. This acceleration is also inversely proportional to the mass of the system experiencing the net force. Mathematically this is expressed as,

$$F_{net} = ma$$

We see that the second law quantifies the definition of force so that if we can measure mass and acceleration (from our fundamental concepts of mass, length and time) we can then determine what force must have produced that acceleration. The units of force must be Kg m/s^2 to be consistant with the expression above. Physicists have given the name of Newton to this unit of force. Thus 1 Newton = 1 Kg m/s^2. In the English system the unit of force is the

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CHAPTER 4 -- DYNAMICS --- FORCES

Our discussions thus far have focused on the description of motion without regard for the reasons for that motion or change in motion. The area of Physics called dynamics deals with the cause of change in motion. Sir Isaac Newton was the scientist credited with laying down the cornerstones of this field. This cornerstone comes in the form of three statements now known as "Newtons Laws".

NEWTON'S FIRST LAW

An object will remain at rest or move with constant velocity unless acted upon by a net force.

The First Law tells us that the natural state of an object is either one of rest or constant velocity. Prior to Newton people believed that rest was the only natural state and that all objects will slow down unless they are being pushed. Newton postulates that forces are required to change velocity.

The First Law thus gives us the first idea of what a force is, i.e. it is that which changes an objects velocity (or that which accelerates an object). We think of force as a push or a pull since pushes or pulls will accelerate objects. The statement uses the words "net force" and by that it means that we must sum all forces acting on an object, using vector methods if necessary. If this net

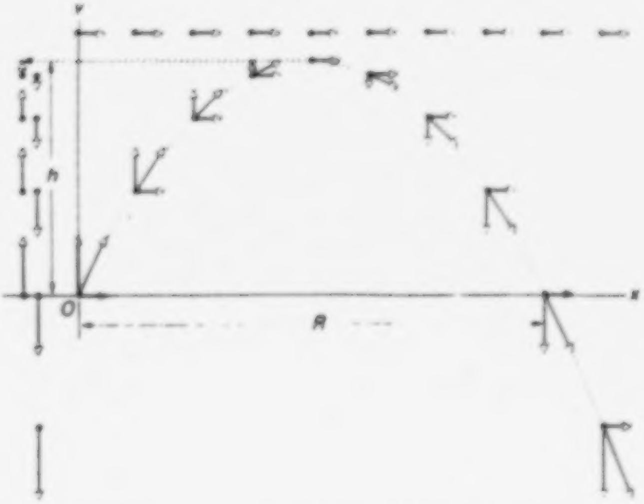


Figure 3-5. Projectile Motion

(accelerating) vertical component of velocity. The actual arrow is represented by a dot, the arrows in the figure are the vector velocity or its components.

shows one such apparatus "The monkey hunter". In this demonstration the monkey (actually a teddy bear) is released from its support simultaneously with the release of a projectile directed at the bear from across the room. Since the motion of the projectile in the horizontal direction does not affect the acceleration of gravity both teddy bear and projectile fall to earth at the same rate and so when the projectile reaches the position of the teddy bear they have both fallen the same distance from their initial elevation and a collision results.

Now returning to the example of an arrow shot at an angle; if we resolve the initial velocity into vertical and horizontal components, we then see for the horizontal component of the arrows motion a constant velocity in the x direction for all time. That means that Equation [2] of chapter 2 becomes $x = v_{ox}t$ where v_{ox} is the x component of the initial velocity. Meanwhile in the vertical direction the arrow is traveling identically with that described in Example D of chapter 2. It´s initial velocity in the y direction, v_{oy}, is first slowed down by the downward acceleration of gravity until at the top of its path it has 0 velocity. The constant downward acceleration of gravity now begins to increase the velocity in the negative, (downward) direction and it uniformly gains larger negative velocities. Figure 3-5 shows a picture of the two motions going on simultaneously. Note the constant horizontal component of the velocity vector and the changing pound and the unit of mass is rather obscure but called the slug, so that 1 pound = 1 slug ft/s^2. The confusion between force and mass is compounded in our society by the common thinking that pounds (a force) is the same measure as Kilograms (a mass), they are not. However, we can measure the force of gravity in either Newtons or pounds, at the surface of the earth, on a mass measured in kilograms, in either Newtons or pounds. We define the weight of an object as the force of gravity on its mass. Since weight is a force its units are Newtons or pounds while mass is measured in kilograms or slugs. Note also that objects will weigh differently in different gravitational fields, such as on the moon, but an objects mass is the same everywhere in the universe.

Applications of the second law will be considered shortly but first we will look at the Third Law of Newton.

NEWTON´S THIRD LAW

For every force (action) on A due to B there is an equal and opposite force (reaction) on B due to A.

This statement shows us that forces always act in pairs. One object cannot exert a force on another without that other exerting an equal and opposite force on the first. This is often referred to as Newton´s action-reaction law. Its greatest usefulness is in identifying forces on an object of interest. For example if we exert a force on the floor in order to walk forward, we know that the floor pushing on us is one of the forces that determines our motion.

First law examples - A heavy ball is hanging from a support by a string, a similar string is tied to a hook on the bottom of the ball and hangs out below, see Fig. 4-1. A downward force is applied to the lower string and gradually increased until a string breaks. Which string breaks? Let us begin by looking at the forces on the ball. The ball is being lifted up by the upper string, T1, while gravity, W, and the lower string, T2. are pulling it down. Thus since before the string breaks there is no acceleration there can be no net force. Or T1 - W - T2 = 0. If we rearrange this expression we get T1 = W + T2, which tells us that the upper string will always be stretched more strongly than the lower one and thus it should break first. In class we showed that if we pulled the lower string very fast the lower string broke before the upper. This was because at the high speed the ball could not move enough to transmit the tension to the upper string before the lower string had exceeded its breaking point. A second

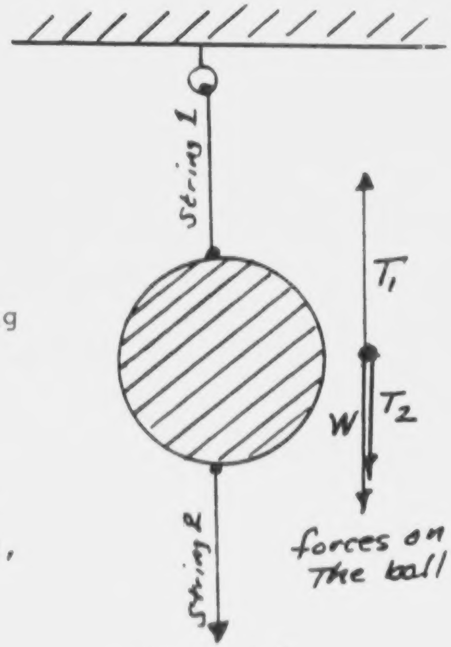


Figure 4-1

demonstration was that of pulling the table cloth out from a place setting of dishes etc. If the table cloth Figure 4-1 is pulled slowly the force of friction between the cloth and the dishes is large enough to move the dishes with the cloth, however if the cloth is pulled very quickly the dishes do not receive sufficient force to accelerate at the rate of the tablecloth and the cloth is gone before they have moved significantly.

Both of these examples show the tendency of objects to remain at rest unless acted on by a force sufficient to produce the required acceleration (this tendency is many times called the object inertia). In the first example the force necessary was greater than the strength of the string and in the second case the force was greater than friction could provide so the tablecloth slipped out from under the dishes.

Second Law Example - 1200 Kg tractor is pulling a 400 Kg log with a cable, see Fig. 4-2. The cable exerts a force of 2000 N on the log and there is a force of 800 N required to pull the log over the ground. Find the acceleration of the log and tractor.

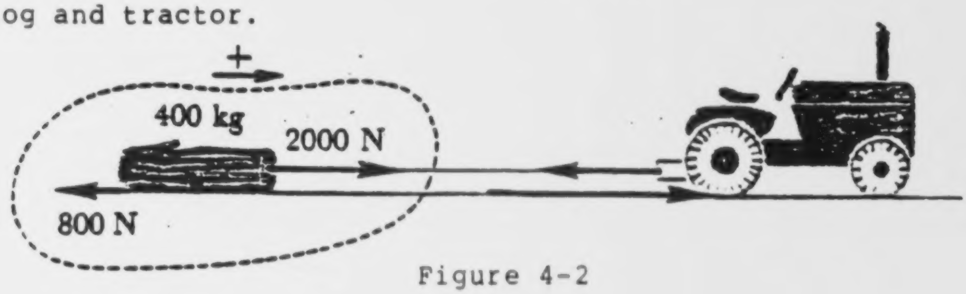


Figure 4-2

First we focus our attention on the log. What forces are acting on the log? Since the motion is horizontal we need not concern ourselves with vertical forces. There are only two horizontal forces acting on the log, the force of the cable which we call the tension, T, and the force of friction F_f. Thus the net force is;

$$\begin{aligned} F_{net} &= T - F_f \\ &= 2000\ N - 800\ N \\ &= 1200\ N. \end{aligned}$$

Now Newton´s second law permits us to calculate the acceleration of the log by;

$$F_{net} = ma$$
$$1200\ N = (400\ Kg)\ a,$$

or, solving for a, we get;

$$a = 1200\ N\ /\ 400\ Kg$$
$$a = 3\ m/s^2.$$

This is the acceleration of the log or tractor since they are moving together.

We might also ask what is the force of the tractor wheels on the ground to do this job. We can answer this by shifting our attention to the tractor. The forces acting on the tractor are the pull of the cable, T, which by action-reaction is pointing opposite to the direction of motion, and the force of the ground on the wheels, F_{wheel}, which is the source of the forward motion of the tractor. For the net force we get;

$$F_{net} = F_{wheel} - T,$$

or

$$F_{wheel} = F_{net} + T.$$

From the second law we can replace the net force with (Ma) where M is the mass of the tractor so;

$$F_{wheel} = Ma + T$$

$$= (1200\ Kg)(3\ m/s^2) + 2000\ N$$

$$= 5600\ N.$$

Third Law Example - We have used the third law several times in the examples above but we will point out one further application from the example above. If we look at the log and tractor as a single object and ask what forces are acting on that object we see that there are really only two because the force of the cable at one point in our system is equal and opposite to the force of the cable at another point in the system. Thus the cable forces cancel out and the force of the wheels minus the frictional drag of the log becomes the net force on the system. We must be careful at this point to note that the mass of the system is the sum of the mass of the log plus that of the tractor (i.e. 1600 Kg). The second law would then say;

$$F_{wheel} - F_f = (m + M)\ a$$

$$5600\ N - 800\ N = (1600Kg)(3\ m/s^2)$$

$$4800\ N = 4800\ N.$$

The fact The fact that both sides are identical proves that our analysis is consistant whether we focus on the log, the tractor, or the combination.

CHAPTER 5 -- WORK AND ENERGY

In our everyday use of the work we have a broad range of uses from our employment of job to those activities that tire us of the results of ones effort. In physics our definition will relate to some of these concepts but it is much more specific than the range of meaning in our language.

In Physics our definition of work is that if we move an object with some force through some distance work has been done. The amount of work is given by the product (force) (distance) where the force used must be the component of the force parallel to the direction of motion. Algebraically this is expressed as;

> Definition -- $W = F_x x$, for motion in the x direction, if the motion were in the y direction then the work would be $F_y y$.

The implication here is that work is not done unless the force produces a change in position. If you hold out your arm to the side with a book in your hand no work is done on the book as long as it does not move. Even after you get tired and your arm begins to hurt from maintaining that force you are not doing work on the book, because there is no change in position. The physiology of how the body provides the force through chemical energies is a digression you might like to study but one we cannot go into in this course.

Work against gravity is one of the most common tasks we do. Since gravity permeates the space about us we cannot escape its demands. If we were to lift a watermelon, say of mass 10 Kg from the ground to the table a height of 70 cm we ask what would be the work required? We know that the force to lift 10 Kg is roughly (10 Kg)(10 m/s^2) or 100 N. Thus the work to lift the watermelon must be; (100 N)(0.70 m), or 70 Nm.

The units of work come out in Nm (Newton meter) and this unit is commonly given the name of joule. Thus we would normally say that the work expended to lift the watermelon is 70 j. In the english system the units for work are simply, foot pounds. Be careful to not confuse the units of work with the units of torque. The units of work are dimensionally the same, but mean something quite different. Torque is always force times a perpendicular distance and work is force times a parallel distance.

The concept of energy is closely related to that of work. Energy is seen as having the capability to do work, or stored work. For example if we lift the watermelon to the table the watermelon, by virtue of its raised position, has the capability of working on something else as it returns to the floor level. This energy of position is called Potential Energy, PE. A change in potential energy can be calculated by finding the work required to accomplish the change in position. In our example the watermelon required 70 j to be lifted to the table so we say it has

70 j of PE with respect to the floor. Note that we only know how to find changes in PE, the zero of potential energy is not defined. By and large we will choose the zero to make our calculations easier. For the watermelon problem calling the floor zero is convenient, however if we have a deep hole in the floor and want to consider dropping the watermelon down the hole we might choose the zero of PE as the bottom of the hole. This choice is not necessary because we can just call the PE minus as the melon goes below ground. The zeropoint is entirely arbitrary.

> *Definition* -- The potential energy of gravity on the surface of the earth, $PE_{gravity}$, can be calculated by; $PE_{gravity} = mgy$, where y is the vertical position above the selected zero of PE, m is the mass of the object and g is the acceleration of gravity.

Another form of energy is that of motion of Kinetic Energy, KE. An object, A, that is moving can exert a force on another object, B, and move object B, as it, A, slows down. Thus the motion of A has performed work on B at the expense of the A motion. To better understand this let us consider the work done by a net force in the x direction.

$$W = F_{net}\ x.$$

From Newton's second law;

$$F_{net} = ma$$

so that;

$$W = ma\ x.$$

From our fourth kinematic equation (see Chapter 2),

$$v^2 - v_o^2 = 2\ a\ x,$$

we get;

$$a\ x = (1/2)(v^2 - v_o^2).$$

We recognize this (a x) as appearing in the expression for net work above so we substitute to get;

$$W = m\ (1/2)(v^2 - v_o^2).$$

This is usually rearranged to;

$$W = (1/2)mv^2 - (1/2)mv_o^2.$$

We now see that our work with the net force has produced a change in motion where the quantity $(1/2)mv^2$ is our measure of the work. We can now define kinetic energy;

Definition -- Kinetic energy, KE, is calculated by;

$$KE = (1/2)mv^2,$$

and work by a net force is;

$$W - KE - KE_o.$$

Someone might ask what is the KE of the watermelon if it falls from the table to the floor? We note that in falling gravity will work on the melon in the amount mgy, and this amount of work will produce a change in kinetic energy given by;

$$W - mgy = KE - KE_o.$$

If the melon begins with zero KE then we get;

$$mgy = (1/2)mv^2$$

or

$$v^2 = 2\ gy$$

$$= 2(10\ m/s^2)(.70\ m)$$

$$v = 3.74\ m/s.$$ {12.3 ft/s or 8.4 mph}

Another viewpoint of the above discussion is that the potential energy of the melon before it fell is the kinetic energy of it as it reaches the floor. Or if we think of a quantity we call total energy, TE, which we define as;

$$TE = PE + KE,$$

then as the melon falls it has the same total energy but initially it is all potential energy and as it hits the floor it is all KE. Every increment of lost PE is gained KE so that TE is the same throughout the fall. Since at the top $TE = PE = mgy$ and at the bottom $TE = KE = (1/2)mv^2$, our equation is the same as before;

$$mgy = (1/2)mv^2.$$

This new perspective becomes a powerful tool for solving problems.

EXAMPLE A

In class we suspended a bowling ball from a cable in the ceiling. This made a large pendulum which we watched as it swung back and forth. From the point of view of energy we note that at the outer endpoints the ball comes to rest and TE = PE, while at the center the call is at its lowest point which we called zero PE so that TE = KE. At other points if we know the elevation we can calculate the KE and thus the velocity at that height. The ball was held off the instructors nose and then let fall, when it swung back it could not come any closer than its initial position and therefore could not hurt the instructor (if the instructor doesn't move!).

EXAMPLE B

We talked about a ball rolling off of the bench. Say we had a ball rolling at .5m/s on a bench that is 0.80m above the floor. Find the speed of the ball as it strikes the floor. Initially the total energy has two contributions for it has both KE and PE;

$$
\begin{aligned}
TE &= mgy + (1/2)mv_o^2 \\
&= m(10\ m/s^2)(0.80\ m) + (.5)(m)(.5\ m/s)^2 \\
&= 8m + .125\ m \quad \text{(in joules)} \\
&= (8.125)m \quad \text{(in joules)}.
\end{aligned}
$$

Now the energy at the bottom is;

$$TE = (1/2)mv^2,$$

note at the bottom PE is zero because $y = 0$ at the bottom. The total energy at either top or bottom is the same so we equate the two equations;

$$(8.125)m = (1/2)mv^2,$$

so that after noting that mass cancels out

$$v^2 = 16.25\ m^2/s^2,$$

or

$$v = 4.03\ m/s.$$

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

CHAPTER 6 -- ROTATIONS AND CIRCULAR MOTION

CENTRIFUGAL VS. CENTRIPETAL

As we go around a corner in a car it is common to think of a centrifugal force throwing everything to the side of the car that is on the outside of the curve. In physics we call this a fictitious force although from inside the car it seems real enough, from outside the car the situation looks not only different but allows us to see that there is in fact no force in the outward direction. From the frame of reference outside the car we see each passenger moving in a straight line, as the car begins to turn the passengers try to continue in a straight line and the car is pulling out from under them, the only real force on the passenger is the force of the seat trying to force them inward on the circular path. Now we append this by saying that Physicists don't mean that the concept of centrifugal force is useless or wrong, in fact it is considered a useful construct for many purposes but we keep in mind it is not real. The real force that is acting is the centripetal force and it is radially directed inward. All circular motions must have a centripetal force to maintain that path. The size of the center seeking (centripetal) acceleration required to stay on a circle of radius r is;

$$a = v^2/r.$$

Newtons second law tells us the net force required to stay on that path is then;

$$F = mv^2/r,$$

where F is radially pointed inward and is the centripetal force. For planets orbiting the sun the centripetal force is gravity acting between the sun and the planets. If you swing a weight on the end of the string the string provides the pull to the center that keeps it on a circular path.

When a car goes around the corner the force of friction on the wheels provides the force of the earth on the car's wheels that keeps it turning. Occasionally the friction is not sufficient, as on ice, and the car doesn't turn but rather continues on a straight line in a skid. Sometimes highway engineers bank the highway so that a component of the normal force of the road points toward the center of the curve and provides the necessary centripetal force without relying on friction (and thus the quality of the tires). Thus if we go around the curve at the speed it was designed for we won't skid even on glare ice, but if we go too slow we will slide down the bank and if we go too fast we will slide up the bank. Note that many highway departments post curve speeds that are not the exact speed they were designed for so that you can't always tell what the design speed of a curve is.

TORQUE AND ROTATIONAL MOTION

If we apply a force of 10N northward on one end of a long stick and a force of 10N southward on the other end we would first note that the net force on the stick is zero but we would further note that such an action will result in the rotation of the stick about its center. This action that produces a rotation is called a torque.

DEFINITION - Torque about an axis is calculated from the product of the force and the perpendicular distance from the axis to the force.

$$T = F\, r_{perp}$$

Torques that cause counter-clockwise rotations, CCW, will be called + and those that cause clockwise rotations, CW, will be called negative. In general a torque is a vector whose direction needs to be defined but for this course we will suffice ourselves with the + or - sense defined above. When an object is in equilibrium not only its forces must be zero but also its torques must be zero. When two students are on opposite ends of a teeter-totter and are balanced we say their torques sum to zero or there is no net torque. If student A has weight W_A and sits x_A to the left of the center support and student B has weight W_B and sits x_B to the right of center as we view them from the side. The torque of student A is positive (force down on the left is CCW) and given by $(W_A)(x_A) + (-W_B)(x_B) = 0$ which can be rearranged to; $(W_A)(x_A) = (W_B)(x_B)$.
This is many times called the law of the lever but it is just the balance of torques requirement.

If the torques do not add to zero, rotational acceleration results, and an equation very analogous to Newtons second law describes that response.

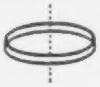
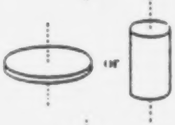
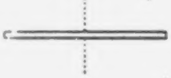
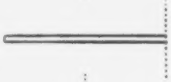
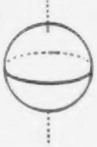
NEWTONS 2ND LAW FOR ROTATIONS

$$T = I\ (a/r),$$

where I is the moment of inertia and plays the role of mass (inertia) in rotations. The factor a/r is a measure of angular acceleration where a is the acceleration at any point r from the center.

The above relationship describes the response to a torque in the same way that F = ma describes the response to a force. In class we applied a torque to a bar with masses on it that accelerated rapidly when the masses were near the center of rotation and it accelerated slowly when the masses were out near the end. From this we concluded that the inertia to rotating systems depends not only on the mass but how far that mass is from the center of rotation. This is the concept of moment of inertia, moment of inertia is always proportional to mass and the square of a dimension. Table 6-1 below shows some typical moments of inertia for your comparison. Note that is it important to observe your axis of rotation, as different axis will have different moments of inertia for the same shape. By comparing the first two examples we see that when all the mass is in the outer edge as in the ring the moment of inertia is larger than when it

Table 6-1. Moments of inertia for several symmetrical shapes around specific axes.

Thin ring, axis through center		$I = MR^2$
Solid uniform disk or cylinder, axis through center		$I = \frac{1}{2}MR^2$
Thin uniform rod, axis through center		$I = \frac{1}{12}ML^2$
Thin uniform rod, axis through one end		$I = \frac{1}{3}ML^2$
Uniform solid sphere, axis through center		$I = \frac{2}{5}MR^2$

is at a smaller radii as in the uniform disk where it is half as big. The method by which these values are calculated is unimportant in this class but the qualitative feeling for where the mass is distributed and its impact on I should be noted.

ANGULAR MOMENTUM

Just as we had a momentum statement of Newtons second law; $F = (P - P_0)/t$,

we now have its rotational equivalent in angular momentum, L, where $L = I\ (v/r)$. That expression is;

$$T = (L - L_0)/t.$$

Torques change angular momentum the same as forces are required to change momentum. If we have no torques on a system then its angular momentum cannot change (It is constant or conserved). This is the principle of conservation of angular momentum.

EXAMPLES

Our first example of conservation was as the instructor sat on the bar stool he gave himself some initial angular momentum while his arms were extended with masses in them. As he pulled the masses closer to his body the velocity of rotation increased, if he reextended them he slowed down. Now recall that the angular momentum has to be constant during all this because no torque is being applied. Thus (I(v/r) does not change, if the instructor changes his I then (v/r) must change correspondingly so that their product, L, remains the same. As the masses are pulled in the moment of inertia is reduced so that (v/r) must be larger. If the masses are put at large radius I is larger and (v/r) must be smaller.

For the second example we had some weights on the end of levers. As we spun the weights around and watched them change velocity as we pulled them in or let them out, we again noted that the small moment of inertia gave a large angular velocity.

The third example demonstrated how a gyrocompass works. Since angular momentum is conserved when no torques are applied, we can set a wheel in rotation and its axis will point in the same direction no matter how our direction changes with respect to that motion. We therefore have a device that continually points in the direction it was started in. Note that this an absolute direction in space and so even the rotation of the earth may be evident in the orientation of the gyrocompass. This becomes its merit in space navigation because its direction does not depend on the presence of earth. We also noted that if we supplied a torque on this spinning wheel its response was not in the direction of the applied force but rather perpendicular to the plane of the force and the axis of rotation. This is why when bicycles are moving very fast (and even more so motor cycles) they become difficult to steer by turning the handlebars, but are easily steered by shifting the body weight. The torque of tipping causes the wheel to respond by turning (sometimes called precessing) in the desired direction but applying a torque to the handle bars induces a rotation that works to tip the bike over or at least make it feel very skittery.

ROTATIONAL KINETIC ENERGY

The final analogy to linear (or translational) motion that we studied previously (Chapters 4,5) is that of rotational kinetic energy. By now we should be used to writing angular analogue equations:

$$KE_{rot.} = (1/2)\ I\ (v/r)^2.$$

Note that in conservation of angular momentum examples such as your instructor sitting on the bar stool, since angular momentum I (v/r) was constant but we noted changes in (v/r) the $KE_{rot.}$ must have changed. If we think for a moment we realise that this makes sense because it takes a significant force to pull the masses inward and thus change the moment of inertia. It is that work that we do pulling the masses inward that produces the increased $KE_{rot.}$. Thus although angular momentum is conserved (or a constant) the rotational kinetic energy is not conserved because work must be done to move the masses, and that work changes the rotational KE. Rolling without slipping Many times we look at systems where rolling is involved and we need to describe that process carefully. If the center of the wheel is traveling forward with a velocity v then the outer most edge of the wheel is rotating with such a velocity that the lower most point is moving backward with respect to the center of the wheel with the same speed v. This means that the ground and the edge of the wheel are moving with the same velocity with respect to the center of the wheel and thus they are at rest with respect to each other i.e., there is no slippage. Thus the angular velocity (v/r) of the bike wheel and the speed of the center of the wheel with respect to the ground are easily related when we are rolling without slipping. The v in (v/r) is the velocity of the center of the wheel as it rolls without slipping.

CONSERVATION OF TOTAL ENERGY

As we consider the total energy of a rolling object we now recognize that there will be a kinetic energy of the wheel as it moves forward as well as a rotational kinetic energy because it is spinning. We are permitted to split the kinetic energy into these two parts. The first we call

Translational Kinetic Energy, $KE_{tran.}$, and we identify it as the kinetic energy of the center of mass of the object. The second part deals with the rotation about the center of mass and that is the $KE_{rot.}$. Our expression for conservation of energy is now;

$$TE = PE + KE_{tran.} + KE_{rot.}.$$

Thus for objects rolling down the hill from the same height, they will all have the same total energy. If one develops more rotational energy it will develop less translational energy and thus move more slowly down the hill. On the other hand if it has less rotational energy it will then develop more translational energy and move down the hill with a higher velocity. Note that for two objects of the same mass rolling with the same velocity the one with the larger moment of inertia will have the largest rotational energy. Therefore, when predicting which objects will roll down a hill the fastest we need only look at the moment of inertia to see which object will have the larger or smaller rotational KE.

CHAPTER 7 -- TEMPERATURE AND HEAT

At this point we take a new tack and begin a different topic. Up to this point our fundamental concepts of mass, length, and time were adequate for every new concept we developed. To enter the topic of heat and temperature we must introduce a new fundamental concept, that of temperature.

Our earliest senses include the awareness of temperature and we are aware of hot cold differences. To quantify these observations we note that there are some physical phenomena that occur at precise and repeatable temperatures. We can use these phenomena to define a numerical scale and then if we can find a physical property that varies with temperature we can calibrate that property to give us the proper measure at the standard points as well as find a measure for intermediary points. For example we note that the freezing point and the boiling point of water seem to occur at fixed temperatures at least with some controls like standard air pressure and water purity. We might define, as was done historically, the freezing point of water to be 0 and the boiling point to be 100. We then look for an object or system whose properties vary with temperature such as the volume or length of a substance. Say we are looking at the volume of a liquid trapped in a narrow glass tube. We put that tube in contact with melting ice and put a mark on the tube that corresponds to the volume at temperature 0. Then we put the tube in boiling water (at the standard pressure) and a mark on the tube that corresponds to the volume at temperature 100. We now divide the space between the two marks into 100 equal spaces and we have a thermometer that can measure temperatures between those two temperatures. We can also add marks of the same size above and below 0 and 100 to measure temperatures above or below the range we originally defined. This works as long as we don't get so cold that we freeze the liquid in the glass tube or so hot that we boil that liquid.

CELSIUS AND FAHRENHEIT

Our two most common scales are the Celsius and Fahrenheit scales. Celsius is the temperature scale of the metric system and thus the scale used most commonly throughout the world. Fahrenheit is the english system scale and thus the one most commonly used in our day to day experiences.

The Celsius scale (previously called centigrade) or ^{o}C was defined, as we did in our example above, with 0^{o}C being the melting point of ice and 100^{o}C being the boiling point of water. However the scale is now defined by there being 273.15 C^{o} from absolute zero up to the triple point of water and the triple point of water is at -.01^{o}C. The concepts of absolute zero and the triple point of water are to be discussed later but at this point they are mentioned as experimentally observable points from which a temperature scale can be defined. This definition yields a scale with the melting point of ice at 0 and the boiling point very close to 100 but these later two points no longer define that scale. Note that as we define the scale we define how large the temperature unit will be as well as where some point of the scale lies with respect to the defining points.

The Fahrenheit scale or $^{\circ}$F was originally defined with 0 as a salted ice temperature and human body temperature as 100. These points were more difficult to reproduce reliably and thus the defining points were shifted to 32 for the melting point of ice and 212 for the boiling point of water. This produced a scale close to the original one but with more reliable defining points. Note that human body temperature is close to the old 100 (98.6) but no longer exactly 100. The choice of 32 and 212 seems rather off the wall without the historical perspective but then so does 273.15 C$^{\circ}$. The primary point here is that one cannot argue that either scale is more logical or sensible to use than the other, the only issue of our nations converting to a different scale is one of whether we will march to our own drummer or conform to the choice of the majority of the world. The survival of our own economic strength will probably have a larger impact in that choice than our personal taste.

Scale conversions are easily accomplished if we consider the way we have defined our scale. Figure 7-1 shows a temperature line on which the points for melting and boiling are shown. We note that the range between melting and boiling for the Celsius scale is 100 C° and for the Fahrenheit scale it is 180 F°. We see that the ratio of Fahrenheit to Celsius is, 9 F°/5 C°. There are almost 2 F° for every C°. In fact this becomes an easy way to estimate conversions from one scale to the other. If you observe the Celsius temperature on a bank reader board double the number and add 32 to get the temperature in Fahrenheit. See if you can do it faster than the bank sign does it. Of course it is easiest when the temperature is close to freezing. You will soon find that you are off by a degree or two because your doubling is an overestimate. To go the other way, (from F to C) you must find out how far from freezing you are in °F, (i.e. subtract 32) then take 1/2 of that remainder and you will have your Celsius temperature. For more accuracy just use 5/9 instead of 1/2 or 9/5 instead of double.

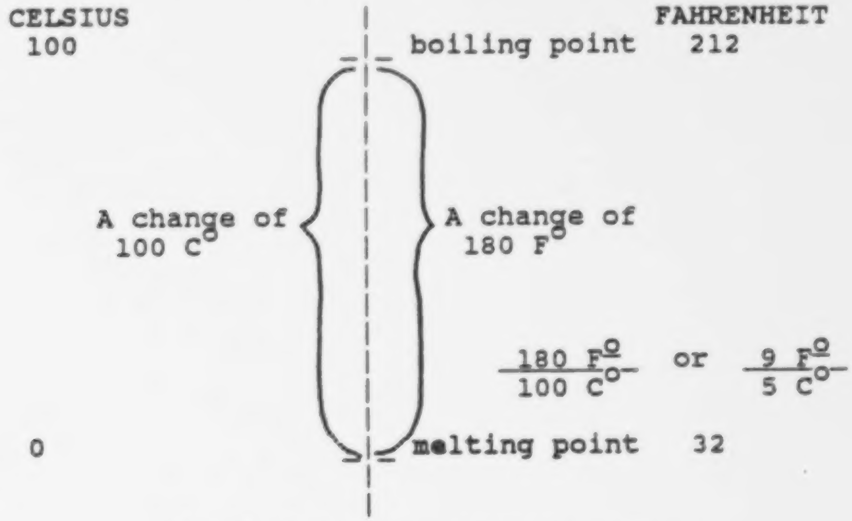

CELSIUS
100
boiling point
FAHRENHEIT
212
A change of 100 C°
A change of 180 F°
180 F° / 100 C° or 9 F° / 5 C°
0
melting point
32

Figure 7-1. Temperature scales

We demonstrated that a set of metal cylinders of identical mass and radius all heated to the temperature of boiling water would melt parafin very different amounts. We then conclude that different amounts of heat are drawn from these cylinders or that different substances of equal mass hold differing amounts of heat for the same temperature change. Thus there is a material property for different materials that tells us how much heat they absorb to change temperature by one degree. This quantity is called specific heat capacity and is defined by:

$$c = \Delta Q/m\Delta T,$$

where ΔQ is the heat required to change mass m of the substance a temperature change ΔT. The old units of heat are the calorie. This unit was chosen so that the specific heat capacity of water is one, or if we take 1 gram of water and raise if 1 C^{o} then 1 calorie of heat has been added to the water. This definition of a calorie is quite different than the calorie that dieters watch. The dieters unit is the same idea (an energy) but it is really 1000 times larger than our definition. Dieters should call their unit a Kilocalorie. We will never use the misnamed calorie in this course.

Up to the middle of the 1800's heat was not seen as an entity that has a relationship to mechanical energy as we have discussed previously, and thus its units developed separately. Since we now recognize heat as a form of energy these old units of calories are more commonly replaced by joules where 4.2 joules equal 1 calorie. We will continue to use units of calories in our subsequent discussions. Table 7-1 shows some typical specific heats.

Table 7-1. Specific heat capacities of a few substances

Substance	Specific Heat Capacity J/Kg C°	Cal/g C°
helium	5190	1.24
water	4186	1.0
ice	2100	0.50
steam	2010	0.48
wood	1700	0.40
air	1050	0.25
aluminum	920	0.22
steel	460	0.11
copper	390	0.093
mercury	138	0.033
lead	128	0.031

A low specific heat capacity (or specific heat) means that a small amount of heat is all that is necessary to raise an object 1 C° while a large specific heat means that a large amount of heat is required to raise the object 1 C°. We now invert our definition of specific heat so that we can find the heat required to raise a given object a certain amount. $\Delta Q = mc\ \Delta T$,

or more commonly,

$$Q = mc\ \Delta T.$$

LIQUID - SOLID - VAPOR

Another important property of materials is their ability to change form. We are fairly familiar with the solid, liquid, and vapor forms of matter. These forms are called phases and there are in fact four phases of matter, the fourth one being the plasma phase. If we add heat to a solid substance we find that it warms up as in the previous discussion until it reaches its melting point. Figure 7-2 shows a graph of temperature versus heat added for water. Note as we start out in the lower left the 1 gram sample of material is a solid (ice) and warms up to its melting point of 0 $^{\circ}$C since $c_{ice} = .5$ cal/g C$^{\circ}$. At the melting point although we add heat the temperature does not change, at this point the additional heat is transforming the material from a solid to a liquid. Note this means that the transition from one phase to the other can only occur when the line on the graph is horizontal (i.e. constant

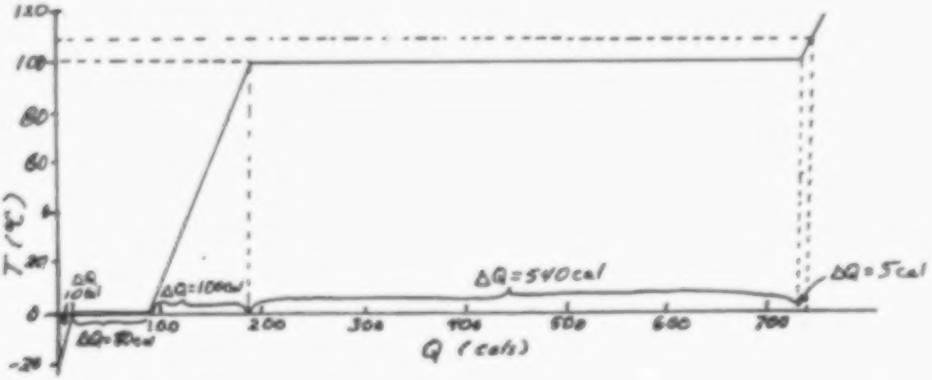


Figure 7-2. Temperature versus heat added for water

temperature while heat is increasing). Here we see that 80 cal were required to complete the transition from solid to liquid for the 1 g sample. As heat is continuing to be added the liquid now responds with increasing temperature. It requires 100 cal to go from 0 °C to 100 °C since $c_{water} = 1.0$ cal/g C°. Now at the boiling point of 100 °C we begin to convert liquid into vapor (or gas) and again the temperature does not change since the energy is being used to transform the phase rather than increasing the temperature. Thus the line is again horizontal until the transformation is complete, some 540 cal later. Further heating now causes the vapor (steam) to get hotter and we note that since the specific heat capacity of steam, $c_{steam} = 0.48$ cal/ g C° it takes 4.8 cal to raise the temp of steam to 110 °C. Although we terminate the data at that point if we continued to heat the steam to higher and higher temperatures at temperatures of over 100,000 °C the molecules would have enough energy to fragment themselves into positive and negative charged pieces and the next phase change, to the plasma phase, would begin. This is obviously an experiment we can't easily watch since no container will withstand those kinds of temperature. Plasmas can be observed in laboratory situations but they are generally created electrically rather than by heating. The uniqueness of the plasma is that it is a mixture of charged particles in a gas like condition. The presence of charge seriously affects the way these particles behave. While plasmas are difficult to observe on earth they are the phase that most star matter is found in so that the most common phase of matter in the universe is that of plasma.

HEAT TRANSFER

Conduction - When we stir our coffee with a silver spoon we note that after a short time the handle is becoming hotter. Since the air around the handle is not that hot we conclude the heat must be coming up the handle from the coffee. This is the process of heat conduction. In general when heat is conducted we find that the heat is transferred from atom to atom as energy, as this energy is passed along from neighbor to neighbor we sense the rise in temperature as the energy arrives and note the conduction process. Different materials conduct heat at different rates so that their heat conduction is another property that can be measured. We will not quantify that process but we noted in a demonstration that heat was conducted down aluminum and copper rods much faster than it was down stainless steel.

Convection - In the previous discussion energy was passed from atom to atom but the atoms themselves did not move any further than their random oscillations about equilibrium. A convection process on the other hand takes the molecules that have the thermal energy and moves the energetic molecules to the position where that energy is desired. Thus convection infers motion of the heated material. Usually convection is subdivided into the catagories of forced convection and natural convection. An example of forced convection is when the furnace creates heat in the fire box it does not warm the house very well so we take a fan and blow the heated air to the parts of the house where it is needed. Pushing the heated air to different locations by a fan is one example of forced convection. Taking a heated stone and placing it near your feet in bed is another example. On the other hand natural convection is a process that occurs only in fluids. By fluids I mean materials that flow, they may be either liquids or gasses. For example a hot stove sitting in one corner of a room warms the air around it as this air gets warm it expands. Since the mass of heated air does not change but its volume increases we see that it has a lower density (Density = mass / volume). Now objects with lower density will float in more dense fluids so the heated air rises up until its density is equal to its surroundings or it hits the ceiling. Since the air has left the proximity of the stove some new cooler air must come in to replace it this air is now warmed until it is lighter than its surroundings and it also rises. As this process continues a current of air is set up called a convection current that continuously moves the previously warmed air away from the stove and across the ceiling where as it cools it returns to the floor level where it moves back toward the stove and reheating. Thus the stove heats the whole room far better than simple conduction could have done. As you heat pans of clear liquids on the stove you can many times observe convection currents as the heated fluid rises from the bottom of the pan cools at the upper surface of the liquid and then falls back to the bottom.

Radiation - The need for a third mechanism of energy transfer is evident when we seek to explain how the sun's energy gets to the earth after traveling through a space where there are almost no molecules, certainly not enough molecules to explain the flow of energy we experience. Radiation is a flow of energy in a wave motion where the wave is an oscillating field rather than oscillating particles. Thus this method of energy transfer does not require the presence of intervening matter. It, however, occurs even when other matter is present so that it is a competing process in that some heat may be lost by radiation while some heat is lost as well by convection and conduction. You can detect the loss of heat of a light bulb by radiation if you hold your hand near the bulb as it is switched on. Immediately you can feel the warmth of the newly lit bulb, as time procedes you will note the surrounding air getting warmer by conduction and convection but that first sense of warmth is the radiation coming to your hand. Different surfaces may radiate or absorb energy faster than others. Objects that are black absorb visible radiation easily and many times absorb the nonvisible radiations as well. If they absorb easily they also radiate easily. Shiny reflective objects on the other hand are poor absorbers or radiaters. This is why your thermos bottle is coated with a mirror like finish. That way it does not radiate away the energy of your heated contents or absorb heat from the surroundings if your contents are chilled.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

CHAPTER 8 -- STATIC ELECTRICAL PHENOMENA

Electrical phenomena have been observed since the beginning of time. In the world around us we feel static cling, zaps as we slide across the car seat, clean dry hair that won't lie down, lightening storms, as well as the electricity that comes out of the wall socket and all that it does. The simplest form of electricity is that produced by rubbing two objects together. For example we take some animal fur and rub it on a black plastic rod and note that both objects are charged. The presence of charge can be detected by that object's affect on other objects. For example the charged rod will attract other objects like a piece of wood that is free to rotate or a styrofoam ball suspended on a string. In one case we took a styrofoam ball coated with a black conductive coating. The ball was attracted to the rod and moved until it touched the rod at the instant of contact the ball was seen to jump back from the rod and then it was repelled by it. We postulate that the charge from the rod was transferred to the ball at the instant of contact and then since the rod and the ball had the same charge they repelled each other. Our experiments went on to show that there were two types of charge in that when we rubbed a glass rod with silk the resulting charge on the glass rod attracted the balls which had been repelled by the black plastic rod. If we then discharged the balls and allowed them to touch the glass rod they were repelled by the rod and each other. We thus concluded that similar charges repel each other and dissimilar charges attract. We chose to follow Ben Franklin's convention that the charge found on the glass rod would be identified as positive (+), and the charge on the black plastic rod would be negative (-).

On the atomic scale this transfer of charge by rubbing is seen as the separation of charge from one atom to the other. Two objects actually strip electrons (or occasionally positive ions) from each other and thus the previously neutral pieces now have a net charge. Whatever positive charge is accumulated on one will be the amount of negative charge on the other.

These charges exert a force on each other that is very similar to the force of gravity. Newtons law of gravitation was $F = GmM/r^2$ as used in astronomy. Note that if you apply this to the force of the earth on objects at the surface of the earth the law can be rearranged to; $F = m(GM/r^2)$. The quantities in the parenthesis are all constants for different objects on the surface of the earth since M is the mass of the earth, r is the radius of the earth and G is the universal gravitation constant. Thus the quantity $(GM/r^2) = g = 9.8\ m/s^2$ and the $F = mg$ that we have used is just a special case of the general law. The force law for electricity is $F = (9x10^9 m^2 N/coul^2)qQ/r^2$, where q and Q are the charges, measured in coulombs, on two objects a distance r apart (from center to center). This law gives us the force on one object due to the other it is a vector pointing away from the other object for positive forces. This means that if the two charges have the same sign they are repulsive and if they are of opposite sign the forces are attractive so that the equation is consistant with our experimental observations. This equation actually tells us how big a coulomb is in that if we have two charges of 1 coul each separated by a distance of 1m they will produce a force of 9×10^{9}N, a very large force. Thus 1 coulomb is an extremely large charge, if we could put that much charge on the two objects we could likely build a structure that could hold the two balls at that distance. If we work with microcoulomb quantities the force will become easily manageable and then a measured force at a given separation will tell us how large the product qQ in (coulombs)^2 is between the two objects. If we had charged the two objects equally the charge on one of the objects is then measured (i.e. the square root of qQ). There are easier ways to measure charge that we will get to, but for now we have a definition.

THE ELECTRIC FIELD

When we talked of a gravitational force we mentioned that our use of F = mg was a special case of Newtons law of gravity where g was a constant on the surface of the earth. We could have called g the gravitational field strength where g = F/m. With this definition g is no longer thought of as a constant but rather a variable that exists throughout space. As a number it will be the acceleration an object will experience at that point of space. Of course across the surface of the earth it is still reasonably constant but as we leave earth and look at other points of space it can vary considerably. Our definition of Electric field is very analogous. Since charge, q, plays the roll of mass in the equation for electrical force we say the electric field, E, is given by; $E = F/q$ or if we know the field at some point the force on charge q at that point is $F = qE$. It is easiest to think of the electric field as the electric force on a charge of +1 coul. The shapes of electric fields around different objects are instructive in terms of where we expect strong or weak electrical forces. Figure 8-1 shows three electric field configurations.

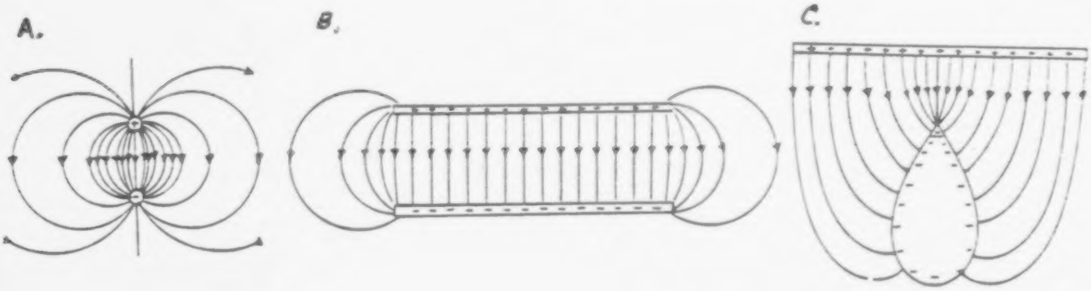


Figure 8-1. Electric Fields of a few shapes

Frame A shows two point conductors of opposite sign, Frame B shows two parallel strips of conductor, and Frame C shows an irregular shaped conductor opposite a flat strip of conductor. We simulated these in class with grass seed in oil and charging provided by the electrostatic generator (sometimes called a van de Graff). The similarity to iron filings and magnets is also striking. The important observations of these drawings are that the electric field lines always enter or leave a conductor perpendicular to that surface. We also note that regions with lots of lines are strong field regions, and regions with only a few lines are weak field regions. For example in Frame A the lines are closest together at the points of the charges where the field;

$$E = F/Q = (9x10^9 m^2 N/coul^2)Q/r^2,$$

is larger because r is smaller. In frame C we see another region of large field around the point.

ELECTRIC POTENTIAL

Since the electric field represents the force on a charge of one coulomb and if we move that charge in that field we must be doing work or creating potential energy. The potential energy per unit charge is defined as the Potential, V;

$$V = PE / q,$$

or

$$PE = qV.$$

We see that potential energy and potential are closely related ideas but that they are not identical. The units of potential are obviously (joules / coul), but this unit is given the name of Volt so that 1 Volt = 1 joule / coul. The volt is our common unit of potential in the US so that in electricity we have already gone metric. Thus particles with high electrical potential are analogous to objects with high gravitational potential like on top of a mountain, and objects with low (or negative) potential are analogous to objects in deep valleys or holes. The high potential point means that charge falling from there can do lots of work but as it does it loses that potential to the work it is doing. One subtlety that should be noted is that a (-) charge at a (-) potential can do positive work, or a minus charge that is at a low or negative potential is the same as a positive charge on top of the mountain it is capable of delivering some work.

CHAPTER 9 -- CURRENT ELECTRICITY (CHARGES IN MOTION)

In the previous discussion we have looked at charge and supposed it to be stationary. Since most of the materials we looked at did not permit motion of the charges we note that materials can be classified by those that permit charges to flow (called conductors) and those that inhibit the motion of charge (called insulators). We certainly recognize there are materials which can transfer charge rapidly such as metals. In this section we will focus on the ability of a material to restrict the flow of charge through itself, a property we call resistance. Before we can define resistance we need to take note of some physical experiments. If we apply a voltage across a material we may observe a current flowing through it. If we choose a conducting material the current will be easily detected. If the material is a good insulator that current may be extremely difficult to measure but it is nevertheless there. For now lets think of the easy case; so our material is a metal say a piece of iron wire. We move charge to one end of the wire say the electrons that are accumulated at the negative end of a battery. If we attach the other end of the wire to the positive end of the battery then the electrons are drawn from the negative end of the wire to the positive end. The battery then lifts them up in energy (remember that minus charge at negative potential is a positive PE) by sacrificing stored chemical energy where they can then retrace the previous path through the wire.

Now if we perform this experiment with a device that tells us how many electrons per second are passing through our wire then we can quantify the charge flow. We call the current, I, the charge per second passing some point in our wire. The units of current are coul/s which is defined as an Ampere. Since we know that each electron carries 1.6×10^{-19}coul then $I = n(1.6\times10^{-19}\text{coul})$ where n is the number of electrons per second. The current will then be in amps. Actually it is easier to measure the current, I, and that is what we will do from here on.

If we connect different voltage sources up to our wire we would find that the current flow was different for each voltage. A graph of voltage versus current will result in data that is, for most materials, a fairly straight line. Figure 9-1 shows such a plot. The larger the voltage across

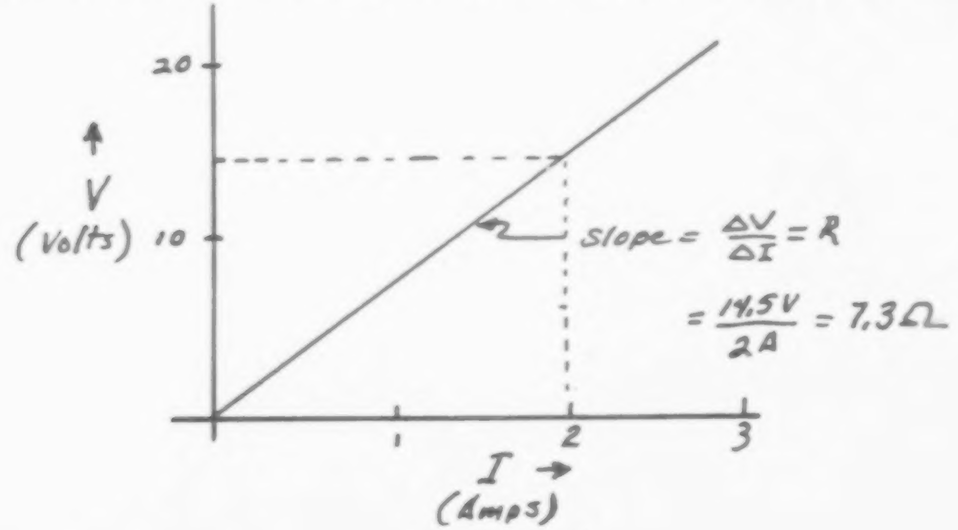


Figure 9-1

the resistor the larger the flow of current through it. This is a demonstration of Ohms Law.

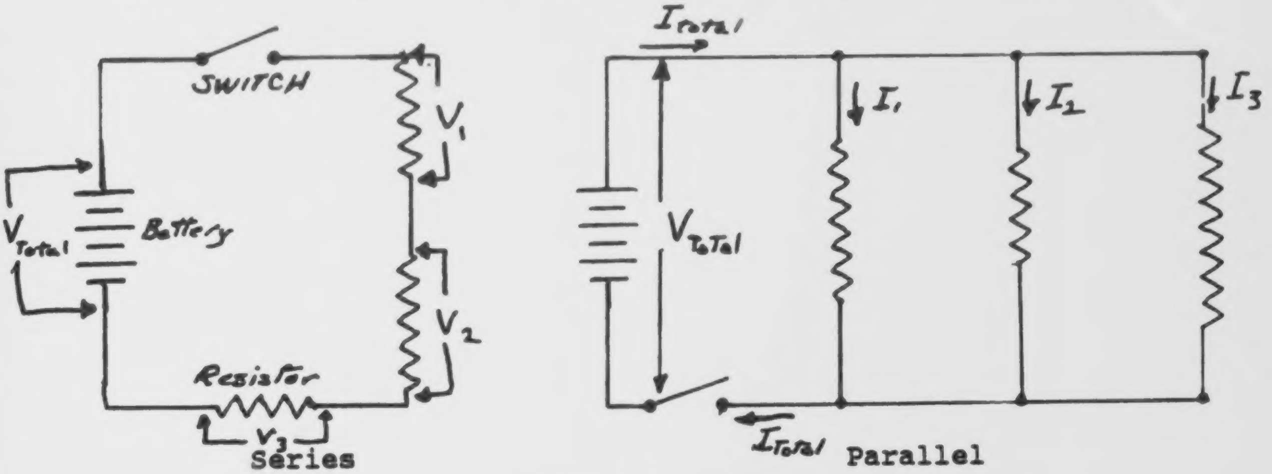
OHMS LAW - The current, I, through an object is usually proportional to the voltage, V, across it. The constant of proportionality is called "Resistance", R. Mathematically it is expressed; $V = IR$. Materials for which R is constant are called Ohmic and those for which R is not constant are Nonohmic.

The units of resistance are (volts/amp) which is given the name of ohm so that 1 ohm = 1 volt/amp. We see that resistance tells us how the current flows for a particular voltage. If the charge is given a particular potential it can fall to zero more easily through a small resistance than it can through a large one so a large current flows through the small resistance and vice versa. Although no material is perfectly ohmic through all extremes of conditions (pressure, temperature for example), most materials are ohmic for a large range of conditions. Most materials become nonohmic when the current through them is large enough to begin heating them faster than the surroundings can cool them.

From the above discussion it is obvious that temperature is one factor that affects resistance. What are other factors that affect resistance? The size and shape of objects is important. For example if we have two identical lengths of wire and we connect one from the plus pole of a battery to the minus pole a certain current will flow if we connect the other wire to the same place the same current will flow through it and thus the battery is losing twice as much current through the two wires as it would through one. If we push the two wires close together so that they become like one wire they still draw the same current so we say that the end area (or cross sectional area) of the wire is doubled and its current carrying capacity is doubled. If for the same voltage a wire carries twice the current then it must have half the resistance so we conclude that resistance is inversely proportional to area. A big pipe can carry more water and a big wire can carry more current.

Another important factor in the resistance is the length of a wire. Again let us think of two identical wires but this time we will connect one end of one to the plus pole and one end of the other wire to the minus pole now we connect the two free ends to each other. Since they are identical they must lose equal amounts of energy or potential. Since the total potential loss across the pair is the original potential, V_o, then the potential drop across each wire must be half of the original potential or (1/2) V_o. That is to say if we had a 12 volt battery there would be six volts across each of the wires. Since they have only half of the potential across them they must have half of the current they would have if they were directly across the original potential. Now the current that flows through one wire leaves that wire and continues through the other wire so that the combined wires carry half of the current while across the potential V_o. The resistance of the combination is thus twice that of either wire. Our conclusion is then that doubling the length of the wire will double its resistance. The two size and shape factors for resistance are the crossectional area and the length. The larger the cross section the smaller the resistance and the longer an object is the larger its resistance. We observed this directly by observing the change in resistance of salt water held in a rubber tube. As we stretched the tube the resistance got larger in part because of the increased length and also because as it stretched it got skinnier, if we pinched the tube the resistance increased due to the reduction in crossectional area of the conduction path.

Electrical Connections - As we connect more than one electrical element to a source of electricity we recognize that there are several different ways that connections might be made. The two most common are identified as series and parallel. Figure 9-2 shows a circuit diagram of these two



Series **Parallel**

Figure 9-2. Series and parallel connections (or circuits)

types of connections. A circuit diagram represents the electrical connections that must be made, however, while in the diagram wires are always drawn in neat straight lines in actuality they need only go from one connection to the other and any route is as good as the other. The wires may twist and wind but the connections are all that matters. Notice also in Figure 9-2 that standard symbols for batteries, switches and resistors are indicated. Note, many times the resistor represents the electrical device we are interested in. Electrically it is only a resistance even though to us it may also be a light, a fan, a stereo, a curling iron, or many other electrical devices.

The series combination shown in Figure 9-2 A is characterized by the fact that there is only one path for electron flow the current that flows through one device must also flow through all subsequent devices. There are no branching points in a series circuit. The driving potential is divided up between the elements of the circuit so that the total of the individual potential differences is the potential of the source (in this case the battery).

$$V_{total} = V_1 + V_2 + \cdots.$$

In this case the potentials V_1, V_2, and etc. are the potential differences of each element in the circuit. Since the current never divides the current flowing at any place in the circuit is the current flowing at all other points.

For the parallel combination we note that the current flow divides into branches some of it going through resistor 1, more through resistor 2 and the remainder through resistor 3. Parallel combinations can split into as many branches as desired. Since it is the current that is divided in the elements of a parallel circuit we note that every element has the same voltage across it but we must sum the currents for the total current provided by the battery.

$$I_{total} = I_1 + I_2 + \cdots.$$

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

CHAPTER 10 -- MAGNETISM AND ELECTROMAGNETISM

The presence of magnetic fields is something that most people have experienced from early childhood. In fact the most common explanation for peculiar behavior of objects is "it must be done with magnets". There is a great confusion among people about the difference between gravity, electricity and magnetism. Many people (non scientists) think of them as the same thing. In this chapter we will show an important and strong connection between electricity and magnetism but they are not the same forces. Can you think of tests to show that gravity, electricity, and magnetism are not the same?

The presence of a magnetic field is easily detected by inserting small bits of iron (filings) in that region. If a field is present the iron will be oriented by the field and that orientation is visually very obvious. For example iron filings are sprinkled around a bar magnet and give a patterns as shown in Figure 10-1. The oriented filings seem to flow from one end of the bar to the other. The two ends of the bars are called poles and as we play around with two such bars we find that in one orientation both ends attract and in the reverse orientation both ends repel each other. As we try different combinations with several magnets we can find that two poles which are attracted to a third pole will repel each other and we come to the conclusion that like

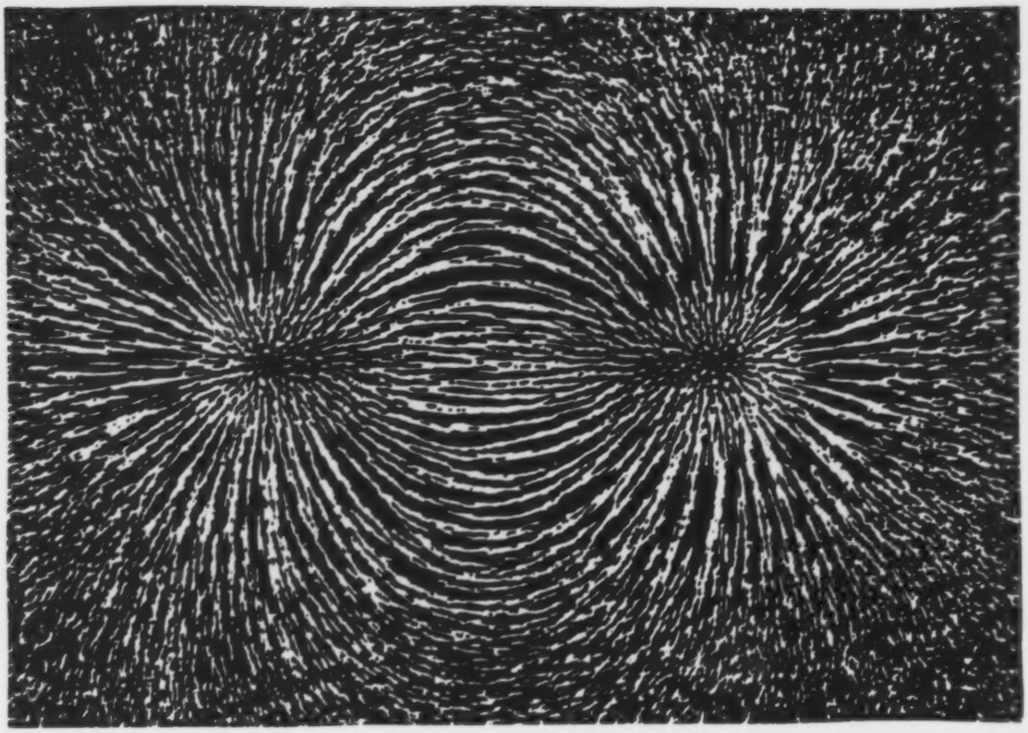


Figure 10-1. Magnetic field of a bar magnet seen with iron filings

poles repel and unlike poles attract. We further note that we can give a direction to the flowing lines of magnetic field we see with our filings. We define the flow as the direction of push on a north pole placed at that location. The two kinds of poles are given the names of north and south because if they are suspended on a slender thread one pole of the magnet will orient itself toward the geographic north on the surface of the earth, the other pole then pointing more southward. Thus a north seeking pole is called a north pole and a south seeking pole is called the south pole of a magnet. This brings us to the most disturbing of paradoxs, that is that since unlike poles attract, all the north pointing poles must be drawn to a south magnetic pole at the north pole of the earth. Thus the earths geographic north pole is a south magnetic pole. Although at first glance this sounds impossible, or to be a contradiction in terms, it is in fact true and once being recognized it is no longer a problem, thats just the way it is. Figure 10-2 shows a sketch of the earths magnetic field. Note its similarity to the field of a bar magnet.

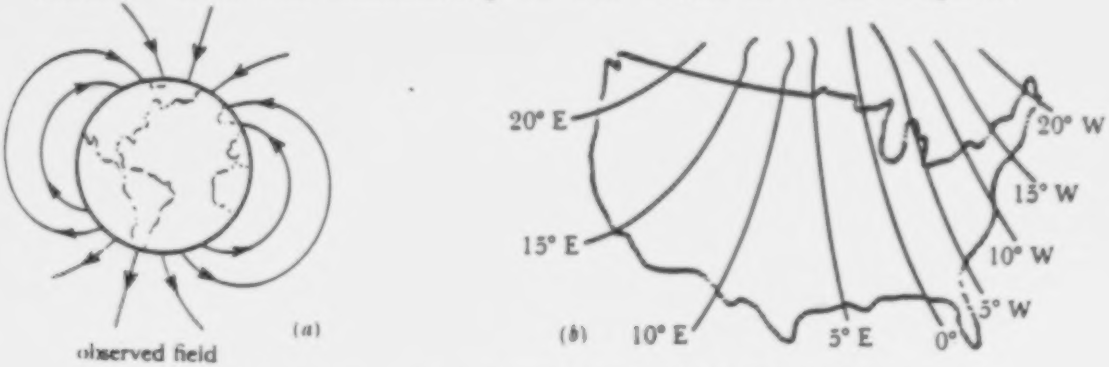


Figure 10-2 A. The Magnetic Field of the earth.
B. Magnetic corrections (declination) for true north in the U.S.

Also note that the magnetic poles are not on the geographic poles. This means that a compass does not point exactly north. In fact in this part of the world it points N20° east of north. If you are using a magnetic compass for navigation you must remain aware of this correction called magnetic declination which varies by quite a bit, see Figure 10-2B. As we further look at the field configuration we note that the field is parallel to the earths surface only near the equator at other lattitudes it has a vertical (or radial) component that in the northern hemisphere is downward (or radially inward) and in the southern hemisphere is upward (or radially outward) from the earth.

MAGNETIZATION OF MATERIALS

We will find that some atoms are magnetized and that is a fundamental property of the atom. Typical strong magnetic atoms are Iron (Fe), Nickel (Ni), Cobalt (Co), and Gadolinium (Gd). Some atoms or molecules that show a weak magnetic field are Oxygen (O_2), Sodium (Na), and Nitric Oxide (NO). The first group are those that we most commonly think of as magnetic (called ferromagnetic) and can be made into permanent magnets while the second group (called paramagnetic) are never found as permanent magnets but can be attracted by a strong magnetic field. We showed in class that liquid oxygen (a paramagnetic liquid) would hang in the gap of a strong magnetic field.

But we are still drawn to the puzzle of why some pieces of iron exhibit a permanent magnetism and other pieces of iron are attracted by a field but are not permanently magnetized. Let us look at the behavior of a collection of small compasses. If we set them close enough to each other so that they interact with each other and then take a bar magnet near the top of the set with enough stirring motion that all of the compass pointers are spinning, and then remove the bar magnet. We note that they slow down and point in a variety of directions but within small regions they point in a consistant direction (see Fig. 10-3a). On the other hand if we slowly draw a pole of our bar magnet near the compasses from right to left and on away the compasses all align in one direction (Fig. 10-3b). This is a good analogy to the behavior within a ferromagnetic material. While all the atomic magnets are alligned with their nearest neighbors there will be regions (called domains) of these oriented atoms that are oriented in different directions. This is the situation for unmagnetized iron in which the domains of alligned atoms are randomly oriented so that there is no net magnetic field on the overall scale but there is magnetic field within each domain. When we expose that unmagnetized iron to a strong magnetic field the domains that are alligned with that field begin to orient the atoms on their boundaries so that those domains grow in size at the expense of their neighboring domains. Thus, after the strong magnetic field is removed, the sum of the fields from the domains is now in the direction of these larger domains and the iron has a permanent magnetic field, it is a magnet.

MAGNETIC FIELDS ASSOCIATED WITH CURRENTS

If we place iron filings or a small compass needle near a wire carrying current we find that there are magnetic field lines oriented in circles that are perpendicular to and centered around the current carrying wire. We thus discover the first link between electricity and magnetism, that moving charges (currents) can create magnetic fields. We then explored several combinations of wires wrapped into coils or spirals and found even stronger fields as we increased the number of windings. Figure 10-3 shows the field for a loosely wound spiral carrying current. We should note that the field looks very similar to that observed for a bar magnet. This becomes our first clue that perhaps all magnetic fields are the result of current loops. Indeed when we think of atomic electrons circulating about a nucleus it is easy to see the origin of magnetic fields from these microscopic current loops. We also find that spinning g electrons produce a magnetic field as a result of that spinning charge. Because of the way that the electrons combine in complicated atoms, for many atoms the combined spinning and orbiting contributions for the electrons cancel out and there is no net magnetic field, but in a few atoms there is not complete cancellation and thus we have magnetic atoms. Virtually every magnetic field we encounter can be explained in terms of current loops, however, some

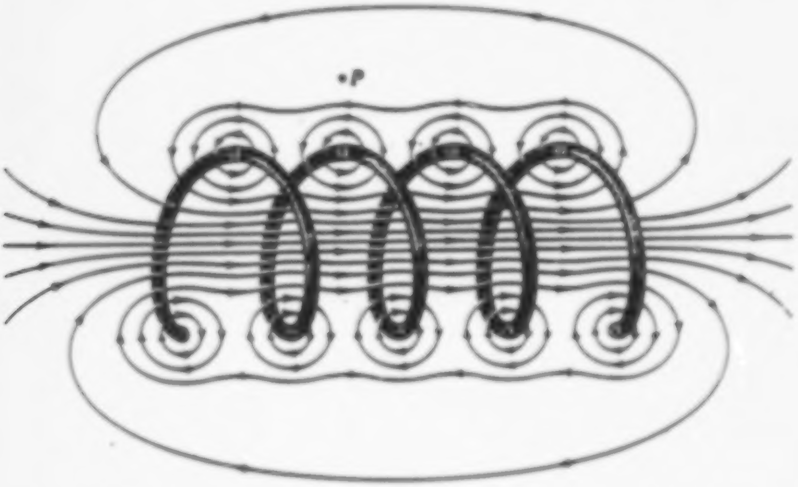


Figure 10.3. The magnetic field of a spiral carrying current

Physicists are still searching for an element of magnetic charge (called the magnetic monopole) that, like an electric charge which creates an electric field, becomes a point source for the magnetic field. Regardless of the success of this search, it is clear that the origin of most magnetic fields that we deal with is due to current loops and is thus always found with two poles.

FORCES ON MOVING CHARGES

The second connection between electricity and magnetism is that if we watch charges move through a magnetic field we find that they are deflected by that field. Magnets located close to electron beams show this very clearly. For example if a bar magnet is held close to a black and white television screen the magnetic field will radically distort the image on the screen (don't try this on color TV because the magnetic field can damage the precision focusing required for color pictures and you will need a repairman to demagnetize your set). The distortion is because the magnetic field bends the electron beam as it approaches the screen from behind and it strikes at a different point than it was supposed to. We can also observe this effect with a current running down a wire in a magnetic field. If the current flows perpendicular to the field the wire will be thrown sideways out of the field perpendicular to both the field and the direction of current flow. If the field is strong enough and the current large enough the effect is quite dramatic. We can capitalize on this effect by running current through a loop of wire in the field so that one side of the loop is pushed down while the other side is pushed up. This coil can be constructed on an axle then where it could be made to spin. This device is the beginning of an electric motor. Special electrical connections are required to keep the motor turning in the desired direction but for our purposes we only note the source of the force that turns the motor is the force on a current flowing in a magnetic field.

If a piece of metal is pushed through a magnetic field the charges (electrons in that metal) will be pushed to the side of the metal. Now forces on charges means that the charge is in an electric field or that the motion of the metal in a magnetic field is generating an electric field or an electric potential. If the piece of metal is a wire, whose length is in the direction of that sideways force, the charges will flow along the wire, and we see that we can generate a current by forcing a wire through the magnetic field. This is the fundamental idea on which a generator is constructed. In a sense this is the inverse operation of a motor in that in a motor we send electricity to the device and it begins to rotate from which we can extract mechanical work. On the other hand if we do mechanical work to turn the coil in the magnetic field we can generate electricity flowing in the coil and thus extract electrical energy.

While the case of the motion of a conductor in a magnetic field has been discussed we also find that motion of the magnetic field with respect to a fixed conductor also produces a potential in that material. That motion can be produced either by moving the source of the magnetic field or if it is an electromagnet turning the electromagnet on or off or by changing the current through that electromagnet. Whatever the reason for the changing magnetic field it will produce a potential in space that will force charges to flow if there is a conductor present. We capitalize on this effect in a device known as a transformer. We apply an alternating plus then minus voltage to a coil of wire. This alternating voltage is the kind of electricity we find in the electrical outlets supplied by the local electric utility, (called AC for alternating current). The alternating voltage applied across the coil causes a current to flow that alternates in direction in response to that voltage. As the current oscillates in the coil the magnetic field also oscillates through the coil first one way through then the other. If we then place another coil near that first coil the new coil will experience the changes in magnetic field from the first coil and the resulting potential from that will cause currents to flow in the new coil. These new currents will also be alternating currents since they are derived from an oscillating field. We also noted Lenses law which stated that the induced current would flow in a direction such that the field created by the new current flow would oppose the change in the field that created it. This basically says that the situation opposes change and any change we impose on the system will result in a response that tries to counter our initial change. If we add another loop to our coil we are adding the potential per coil to that that we had previously. Thus we can increase the voltage out by increasing the number of loops, (sometimes called windings), and decrease the voltage by decreasing the number of loops on the coil. Thus a transformer can change the size of the potential available perhaps down to 6 volts or up to 1000 volts. Whatever we desire can be generated just by changing the number of windings. Note also that this could not work if we used a constant voltage like we get from batteries. It is the oscillating voltage, current, and magnetic fields that are critical to its operation.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

CHAPTER 11 -- PROPERTIES OF LIGHT AND OPTICS

We have talked about the existence of Electric and Magnetic fields and even how oscillating magnetic fields will produce oscillating electric fields or potentials. The simultaneous oscillation of electric and magnetic fields is called an electromagnetic wave and it is a wave that moves perpendicular to the direction of the field oscillation.

At this point we need to discuss briefly the nature of a wave and some of its characteristics. The best example of a wave is that of surface waves on water. When we drop a rock into the lake we see the waves (or ripples) move outward from the point where the rock strikes the surface. These waves form a circular pattern that expands away from the point of impact but centered on it. As we look closely at the motion of the water when waves pass through it we see that the water itself primarily goes up and down, it doesn't move in the direction of the wave's motion. The wave motion is an obvious motion in the shape of the surface of the water caused by primarily vertical oscillation of the water's surface. The waves can be measured in terms of three quantities. The wavelength, λ, of a wave is the distance from one crest to the next crest measured in meters. The frequency, f, of a wave is the number of cycles per second that any constituant of the wave oscillates with. The velocity, c, of a wave is the change in position per unit time of any point on the wave such as the crest or a valley. The frequency is very closely related to another property known as the period, T. You may remember that in our first laboratory we measured the period of the pendulum as the time to complete one cycle of oscillation or one round trip. Thus the period is the time to complete one cycle or thus it is the number of seconds/cycle. The inverse of this number must be cycles/second which was the units of frequency and indeed we can readily convert from frequency to period or vice versa whenever required by $f = 1/T$ or $T = 1/f$. The frequency unit of cycles per second is given the name of Hertz after a famous physicist who worked in the foundations of electromagnetic waves. This unit is abbreviated as Hz and you may note that the dial of your radio has vlues that are in KHz or Mhz which are the frequency ranges in which you can tune your radio. Now if our crest moves a distance λ in one period of oscillation T then the velocity must be $c = \lambda / T$ in meters per second. We can also write this in terms of frequency as $c = \lambda f$. Thus the parameters wavelength, frequency and velocity characterize the waves and they are always interrelated by $c = \lambda f$. While water waves are basically an oscillation that is perpendicular to the direction of the wave motion, other waves can be formed by oscillations parallel to the direction of motion. Sound waves are of this variety the molecules get pushed together in a high density region this comes at the expense of molecules near there thus a depletion of molecules or a low density region. These alternating low and high density regions are the oscillations that become the wave.

Electromagnetic waves are oscillation in the strength of the electric or magnetic field as it moves through space it is a transverse oscillation in that the electric and magnetic fields oscillate at right angles to each other. Figure 11-1 shows a sketch of the oscillation to clarify

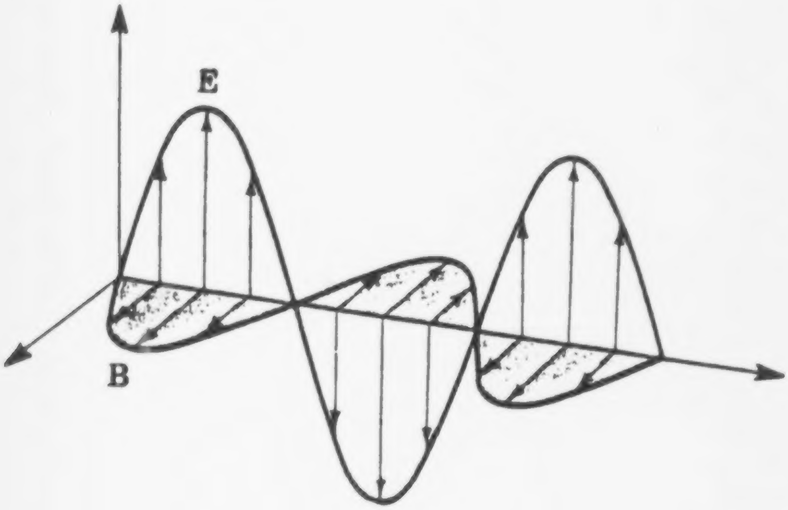


Figure 11-1. An electromagnetic wave

the descriptions we have just given. The wave travels with a velocity $c = 3 \times 10^8$ m/s. This is true for all observers regardless of their motion according to Einstein°s theory of relativity. The paradoxes and complications that that theory creates are fascinating and stimulating but we do not have time to go down that tangent. The wave can travel with a great variety of frequencies or wavelengths. The lowest frequencies we normally encounter are the radiowave frequencies which have a frequency of about 1 MHz for AM and about 100 MHz for the FM band which admittedly don't seem all that low but the higher frequencies include infrared waves around 10 THz (10^{12} Hz = THz), the visible light at 1 PHz (10^{15} Hz = PHz), ultraviolet light around 10 PHz, X-Rays from 100 PHz to 100 EHz (10^{18} Hz = EHz), and Gamma rays on up to 10^{24} Hz. Although this is an extremely long range of frequencies all of the waves are identical in that they are oscillating electric and magnetic fields that travel with a velocity of $c = 3\times10^{8}$m/s. They differ only in their frequency of oscillation and thus also their wavelength.

In this chapter we will focus our attention on that narrow range of the electromagnetic spectrum called the visible light. In frequency it goes from 435 THz to 700 THz and respective wavelengths 690 nm to 430 nm. The low frequency long wavelength end is perceived by the human eye as the color red and the high frequency short wavelength end is seen as a deep blue violet.

REFLECTION AND REFRACTION

As light travels through or against different materials it behaves in some interesting ways that we should begin to look at. Some very shiny surfaces will reflect light and we can watch narrow beams come into and bounce off of surfaces. We note that the beam (sometimes called a bundle of rays or more simply just the rays), leaves the surface with the same angle that it came in on. We usually measure this angle from the perpendicular to the surface and then note that the angle i (for angle of incidence) equals the angle r (for angle of reflection). Figure 11-2 shows such a ray with

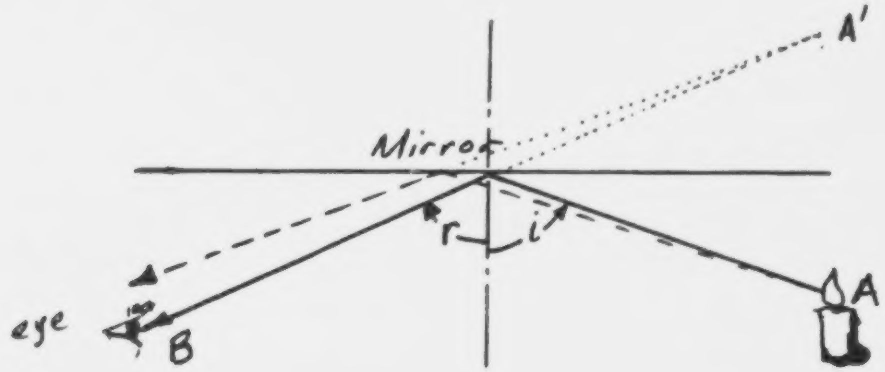


Figure 11-2. Light reflecting from a mirror surface

the angles i and r indicated. An additional ray is dashed in to show how someone looking from point B sees the candle flame at A as though it is at A'. The eye always takes diverging rays and extrapolates back to their source point as the location of the object. Sometimes this extrapolation goes to a place other than where the light actually came from because of some optical device in this case the mirror. When this occurs we say the image is virtual. This is most obvious in the case of a mirror because it is clear that light cannot come from behind the mirror where our image is located.

As light passes into or out of a transparent material we also observe that it can be bent in that passage. For example we show in Figure 11-3 a light ray coming into the

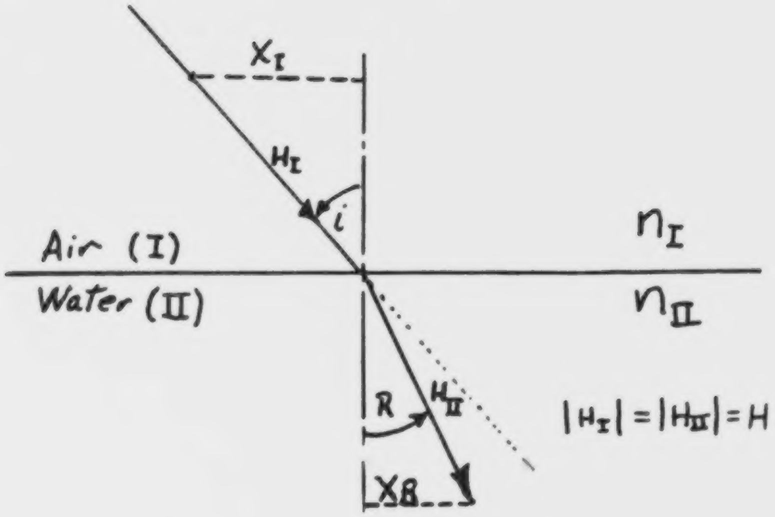


Figure 11-3. The refraction of light going from air into water

surface of water and refracting as it goes into the water. Note again the angles measured from the perpendicular angle i and angle R the angle of refraction. Angle R is rarely equal to i and as we look at different materials we find that for the same i we get different values for angle R. We also find that for different frequencies (colors) we get different angles R for the same angle i. Snell's Law tells us how to predict R for light passing from substance I to substance II.

SNELL'S LAW - Construct two right triangles above and blow the boundary between two transparent substances. The light ray should be the hypotenuse of both triangles and the two hypotenuses should have equal length. One leg of each triangle is the surface perpendicular and the other leg is parallel to the boundary. If the upper leg parallel to the boundary has length X_i and the lower leg parallel to the boundary has length X_R Snells law is;

$$n_I X_i = n_{II} X_R,$$

where n_I, and n_{II} are the indexes of refraction for the two substances.

The index of refraction is a number that can be looked up in handbooks for different materials. Table 11-1 gives some typical values for the index of refraction. The index can never be less than 1.0 and it is rarely greater than 2.0 so that the values in the table reasonably span the allowed range. From Snell's law we see that the larger the index of refraction n_{II} the more the light will be bent in medium II. In the case of the light ray passing into water the ray will be closer to the perpendicular and X_R will be less than X_i. In class we directed a beam of light into a tank of water and onto a submerged mirror and then up to the surface of the water. Since the index of refraction for water is greater than that of air the emerging ray was always further from the perpendicular than the incident ray. As the incident angle was increased the angle of the emerging ray got larger up until it was 90° or thus parallel to the water surface. For larger incoming angles the ray could not emerge and thus it was 100% reflected.

We traced the progression of light through a series of transparent objects and made some observations when light passes through a rectangular object and emerges from the opposite side it emerges with a ray that is parallel to the ray that came into the first surface. This is fairly obvious as we see that the emerging ray from the refraction on the first side will travel to the opposite parallel side where it must follow Snell's Law and refract back to the same direction as initially. When light falls on a triangular shape as in Figure 11-4 the light ray is

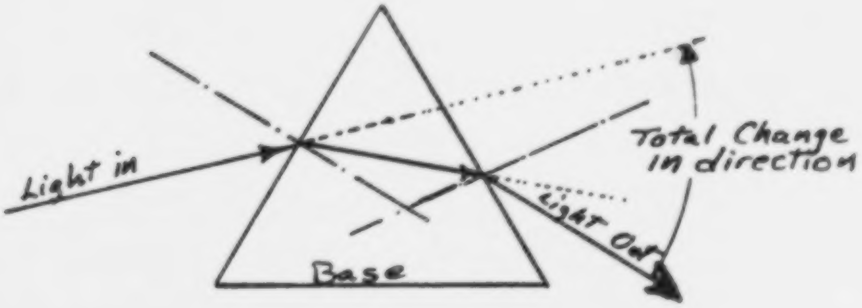


Figure 11-4. The refraction of light through a prism

bent toward the normal (surface perpendicular) as it enters the triangular block of material (many times called a prism). This ray travels on until it encounters another face of the prism where it will refract and emerge being bent away from the normal to that face. The direction of the final ray compared to the direction of the original ray coming in was noted to be bent toward the thickest part of the prism. One should also note that in this bending of the ray different wavelengths had different indices of refraction and thus the final ray is broken up into a spectrum of color. Little glass prisms hung in the window will make beautiful rainbow like patterns from this effect when the sun passes through them.

The most useful shape, however, is that with curved surfaces. As we observed light traveling through a curved piece of material we found that all parallel rays coming into the shape were bent to a common point on the other side. Such a shape (called a converging lens) is shown in Figure 11-5 and the point of convergence of the rays is identified as its focal point, F. We found that such a device could reconstruct the light patterns coming from a source of light, called our object, into an image of that source on the other side of the lens. For many cases that image actually has light coming from there and when viewed from a point beyond actually appears to lie at this image point. This image is called a real image because the light is actually there. We can construct these images with a

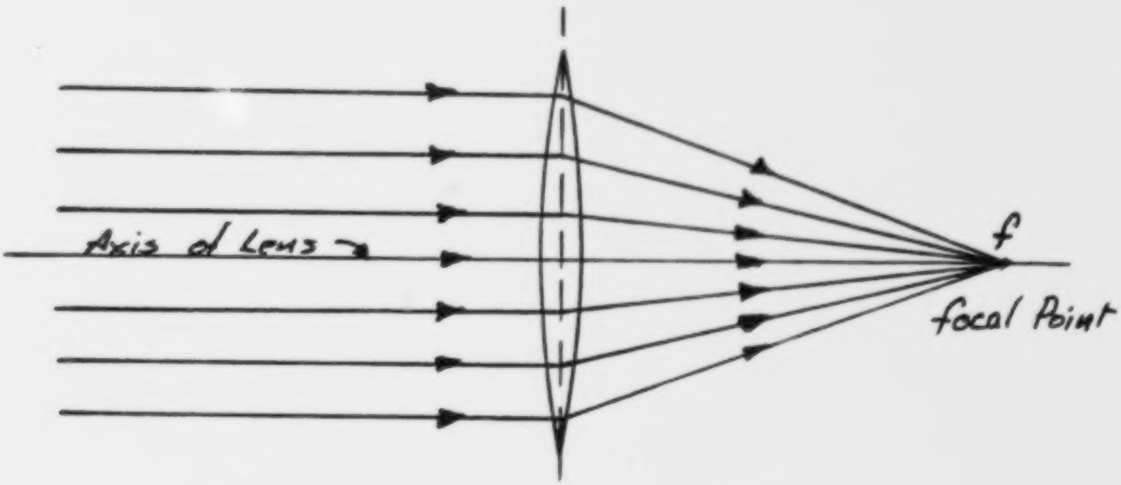


Figure 11-5. A converging lens and its focal point

ruler and a few simple rules. Most objects can be represented by an arrow, since the only important thing is to have some sense of size and which end it up. Figure 11-6 shows the rays commonly used to construct an image from the object on the left. The rays traveling from any point on the object to the lens are all brought to the same corresponding point on the image regardless of which part of the lens the light ray passed through. Of the many rays that pass through the lens there are two which we can account for and once we find a point of intersection for those two we know that all others will also pass through that point as well. The first of these is the parallel ray. The parallel ray is a ray parallel to the axis of the lens and the base of our arrow object. This parallel ray is drawn so that it passes through the tip of the arrow and then travels on to the lens at which point it must bend and pass through the point f, the focal point, and then travel on continuing in that same direction. The other ray is the central ray which passes from the arrow tip through the center of the lens. Since the center of the lens has two

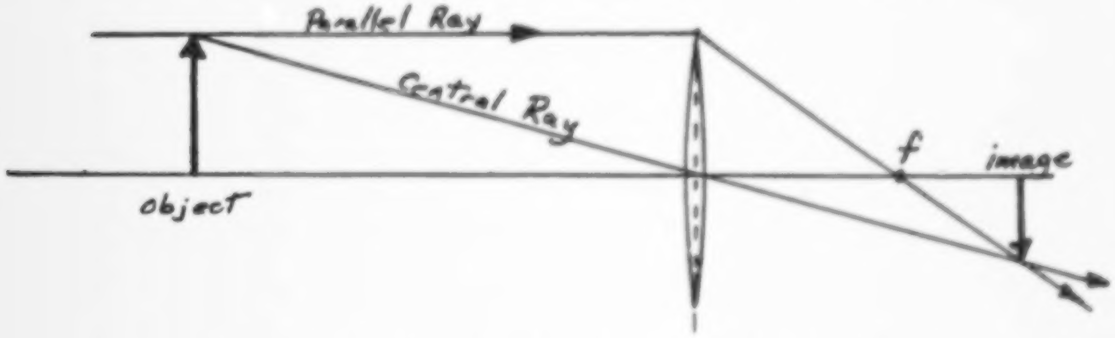


Figure 11-6. Ray tracing to find an image produced by a lens

surfaces that are close to parallel, that ray must travel through the lens without being bent. This ray is drawn on from the lens until it intersects the first ray at which point we say that the tip of the image arrow has been found. There are some cases where the two rays will never intersect and then we extend them to the left to see if they converge on the left. When convergence on the left is found the image is virtual.

Another curved shape is that of a diverging lens (one that is thinner in the center than on the edges). Here we have a lens that must bend incoming parallel rays to wider or diverging angles. These diverging rays can be extended to the left to find a common point, from which they seem to come, called the focal point of this lens. Because it is on the left of the lens (opposite of the focal point for a converging lens) this focal length is given a negative value. Images for this lens can be constructed with the same two rays as above but the parallel ray through the tip of the object is bent outward as it emerges from the lens as though it comes from this lens' focal point. More reading and examples of these image constructions are available in the laboratory notes.

INTERFERENCE EFFECTS-A WAVE PHENOMENON

If we drop two pebbles into a pond simultaneously we can watch the ripple patterns as they interact with each other. This interaction is called interference. You may note that there are regions where the interfering waves have larger peaks and valleys than either wave originally and other places where there is much less action than either wave by itself. In Figure 11-7 we show a representation of the waves we are discussing. The solid rings represent wave crests and the space between them are the valleys of the waves. The regions where the solid rings from both sides are directly on top of each other are regions of increased oscillation or positive interference and the regions where the solid ring of one is on the open ring of the other are regions of negative interference or cancellation. With light waves we see this happen by looking at a distant source of light through two narrow slits or scratches in an otherwise opaque surface. Light through these openings gives an image that is multiple. Instead of one image we have a central strong image and progressively weaker images to either side. The closer our slits are together the further apart will be the images. We

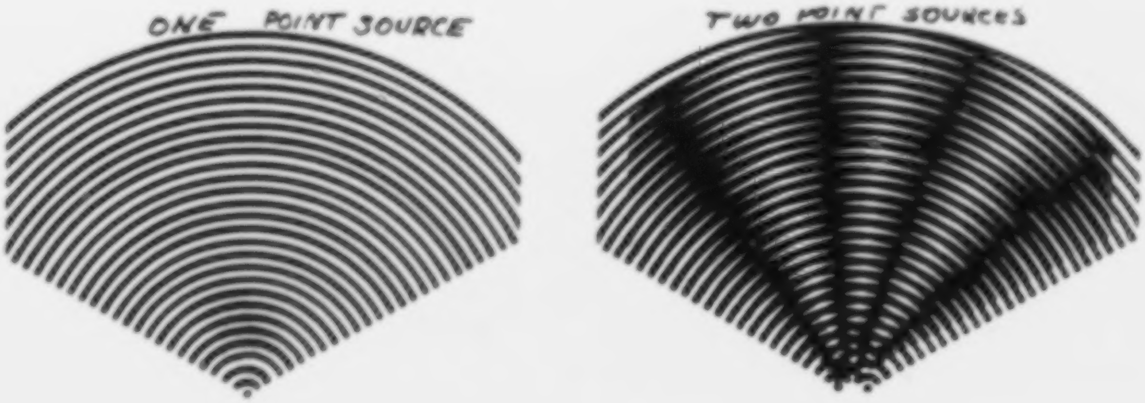


Figure 11-7. Interference of two waves

also directed the laser beam through two slits and saw the spot split up into several spots of varying intensity.

We also found that we could get multiple images from a single slit. While this is harder to understand it is basically an interference effect between light from either edge of the opening. These interference patterns also get further apart as the slits edges get closer together. Once we had seen this effect then we recognized that some of the changes in intensity of our first patterns interference was due to the width of individual slit and other variations are due to the spacing between slits. Since slits are always narrower than the spacing between them the more widely separated oscillations in intensity are due to the slit width and the narrower oscillations are due to the slit separation.

Our final observation of an interference effect was that found for more than two slits. As we increased the number of our slits we found that the patterns became more sharply focused where they were maximum and that they went to zero for longer distances between the maxima. This led to spots that were separated by angles like 10 to 20 degrees. These multiple slit systems are called diffraction gratings and can then be used to break a spectrum up into its components. We observed the spectrum of mercury displayed on the wall from a large multiple grating.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS SECTION

CHAPTER 12 -- ATOMS AND NUCLEI

As turn of the century scientists struggled with the implications of the spectra we have just seen from a diffraction grating, they were bothered by the fact that atoms did not radiate lines except when highly disturbed as in arc discharges, and the reasons for those specific lines which were so different from one element to the other. First let us look at the details of the construction of an atom. We find that the atom is divided into a small central point called the nucleus and a cloud of electrons around it. All the positive nuclear charge is on the nucleus and an equal amount of negative charge is found in the electron cloud so that the atom is normally an electrically neutral species. Since the negatively charged electrons are drawn to the positive nucleus we must explore what other effects are present that prevent the atom from collapsing on itself. The first idea that comes to mind is a planetary model in which the electrons have a rotational motion about the nucleus so that the nucleus provides the necessary centripetal force to hold the electrons in orbits. This model was developed by Niels Bohr but required some rather insightful qualifications to actually describe the simplest of atoms. Another concept also developed in that era that was more successful at describing the behavior of electrons and nuclei. That was the recognition that in this extremely small scale world particles don't behave strictly the way we think of particles behaving in the world of our experience. In our everyday world particle behavior is usually contrasted with wave behavior. Particles travel in straight lines while waves bend around corners. Particles can have any value of energy while waves have resonances at specific frequencies and energies. These everyday distinctions are clearly demonstrated in our macro world but on the microscopic scale the distinctions become considerably more blurred. Thus, this thing we call an electron is capable of wave like behavior as well as its well known particle like behaviors. The rule for converting from particle like properties to wave like properties is that the particle's momentum, p, is related to its wave property λ by $p = h/\lambda$. Here h is called Planck's constant and is 6.6×10^{34} joule sec. Electrons can be diffracted from very fine gratings (usually the periodic rows of atoms on a single crystal surface). We also find that the locality of electrons around an atom are best thought of as standing wave resonances. The space is three dimensional and it is difficult for our minds to picture what that looks like. We looked at standing waves on a ring of wire and found particular frequencies where the waves would resonate and other frequencies for which there was no response. The figures below (Fig. 12-1) show the kinds of standing waves that electrons have near atoms. Figure 12-1 A. is the lowest energy possible for an electron and we see that is a very spherical region centered about the nucleus, while Fig. 12-1 B. shows the next higher energy level with its six lobed maxima separated for ease of viewing but in fact all centered around the

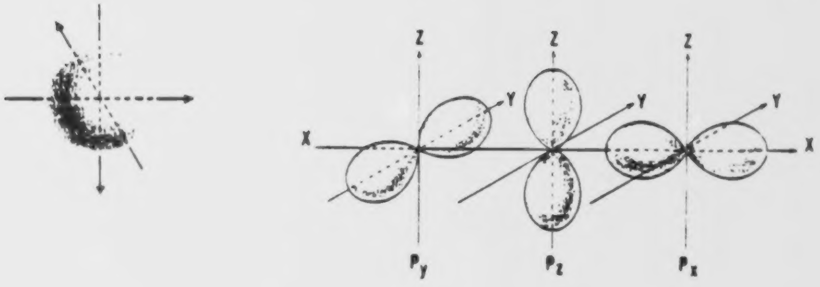


Fig. 12-1. The lowest energy electron standing waves.

nucleus. As we go to higher energies the resonant waves become more complicated but the configurations have been confirmed in many experiments. It is the orientation of these lobes (called orbitals in chemistry) that determines the bonds directions in chemistry and thus the shapes of complicated molecules. When an electron is in a higher energy shape it can drop to a lower one by releasing energy in the amoung of $E = hf$ where f is the frequency of the released wave and h is Planck's constant. This is the origin of the specific spectral lines of different materials. Any time this energy is released it comes as a light wave but because it is released as a discrete entity we call it a photon or particle of light.

THE NUCLEUS

The constituents of the nucleus are called the nucleons. We have found that nucleons may be charged positive or zero. These two categories of nucleons are called respectively protons and neutrons. Figure 12-2 shows a graph of all the nuclei we have

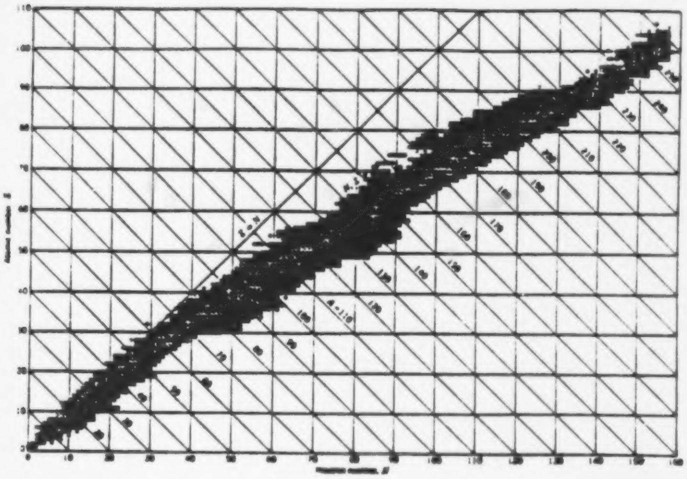


Fig. 12-2. Nuclear stability

observed. The coordinates are horizontally the number of neutrons and vertically the number of protrons. The small solid circles represent nuclei that are stable and found on earth the small open circles are those that have been made in laboratories but are unstable so they don't last very long. We see that there is a large domain of the graph where nuclei have never been observed because they are too unstable to last for a measurement. Thus, the rough line of solid circles is the region of highest stability from this we can see that for very small nuclei the protons and neutrons are about equal in number. As we go to higher numbers of nucleons we note that stability favors more neutrons. This seems reasonable because as we pack more protons into that small space their repulsive force is going to weaken their binding and make the nucleus more unstable. By packing in a few more neutral nucleons the protons are further apart and thus not as strongly repulsive.

An unstable nucleus returns to a stable condition by ejecting different forms of energy. These forms were labeled alpha, beta, and gamma as they were first observed and distinguished. Alpha rays (or particles) travel only short distances from their source and their path can be bent in a magnetic field. Beta rays travel much farther than alphas but still only a few centimeters in air. The path of beta particles is also deflected by a magnetic field but in the opposite direction as alphas. Gamma ray travel the farthest and are not deflected by a magnetic field. Subsequent studies have further identified the alpha particle as a combination of two protons and two neutrons or thus the nucleus of a helium atom. The positive charge of two protons explains the bending of the path in a magnetic field. Beta particles have been identified as electrons and their negative charge explains the opposite bending of their paths in a magnetic field. Gamma rays we have already identified as electromagnetic waves of very high frequency. Since their energy is hf these are also very high energy photons.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 1 Description of Motion

Purpose

The goal of this laboratory is for you to be able to describe qualitatively and quantitatively the motion of objects.

Laboratory Objectives

As a result of this session you will:

1. Describe qualitatively and quantitatively the motion of a given object in terms of position, time, velocity, and acceleration.
2. Develop techniques of measurement.
3. Show how to present data and observations in graphical form.
4. Define and explain the difference between velocity and acceleration.
5. Identify the important parameters of a pendulum's motion.
6. Identify the concepts of this lab as they apply in playground equipment.

Part I Motion

Section A---- What is constant speed?

Introduction

Every day you hear about how fast things go. For example, how much time it takes to get from a class in Fulmer to the CUB, or a police officer informing you that you have exceeded the speed limit. Yet as much as we refer to a concept like speed or velocity, what do we really know about it? What information can the speed of an object give us? We will explore the answers to these questions and bring up some new ones.

Materials

Air track set up (with rubber band replacing the spring on the support), air track glider, masking tape, stopwatch

Procedure

In this section of the lab you will start a glider moving at constant speed. You will describe the motion of the glider. From your observations you will develop a definition of velocity. You will then make measurements to determine if your definition for velocity is correct.

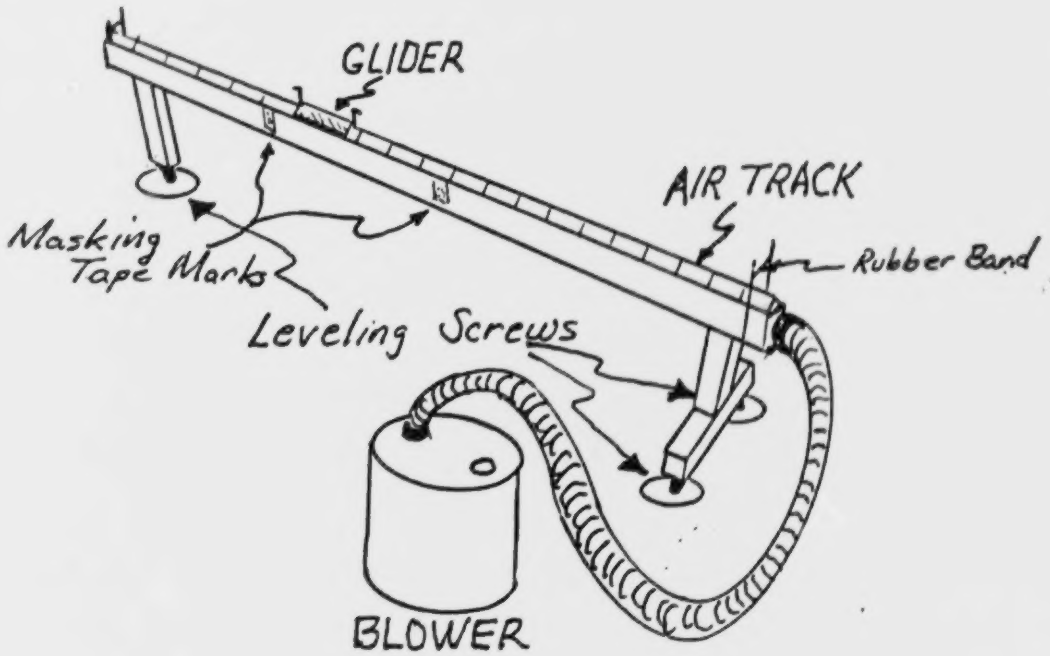

GLIDER
AIR TRACK
Rubber Band
Masking Tape Marks
Leveling Screws
BLOWER

Fig. I.1 Air Track Set-up

Section A.1---- Observations of a glider's movement

1. Leveling the track: Turn on the blower. Place the glider (without the glider weight) in the center of the track. If the glider tends to move to the right or the left you will need to level the track (ask your lab instructor if you need help) until the glider has little or no movement in either direction.

2. Setting the glider in motion: Now put the glider on the track such that the glider is pushed up against the rubber band. Release the glider. The glider should move to the other end of the air track. If not try again. Try to develop a consistent method of releasing the glider.

3. Repeat 2 as many times as you need. Complete worksheet section A.1 for this part.

Section A.2---- Measuring the motion of a glider

4. Setting up to measure time to travel a distance: You will measure the time it takes the glider to move a distance of 120cm. To accomplish this you will first mark off the distance on the air track's scale with two pieces of masking tape. Put the first piece of tape about 25cm in front of the glider when it is at the initial starting position. Place the second piece of tape at the appropriate spot to mark the end of the 120cm distance (these marks will also be used in Section B). Practice releasing the glider such that it takes between 10 to 12 seconds to travel the 120cm distance.

5. Making the measurements: For Table I.A.1 you are asked to find the distance travelled during each successive two second interval. A method of doing this is outlined below.

a. Release the glider

b. Have your partner say 'zero' when he/she presses the start button on the clock. It is best to start the clock when the glider is near the piece of tape 25cm away.

c. When your partner says 'zero' place a piece of tape at the front of gliders present position. This mark serves as the starting mark for your measurements of distance travelled.

d. Place tape at the position of the front of the glider at successive 2 second intervals. It is best to walk along with the glider, so that you can see the position of its front.

e. Complete Table I.A.1 and answer the adjoining questions.

Section B---- What is constant acceleration?

Introduction

Have you ever noticed how your weight changes when an elevator starts or stops? Have you watched how a speedometer "drops" as you slow down for a traffic light or "climbs" when you speed up after a stop? Both of these questions deal with the same concept --- acceleration. We need to ask ourselves the same questions as we did when we considered speed.....

Materials

Air track set up, air track glider, masking tape, one wooden block (19cm x 19cm x 2cm), stopwatch

Procedure

In this part of the lab you will make observations of a glider as it accelerates down an inclined air track. From these observations, you will develop a definition of acceleration. You will then make measurements to determine if your definition is correct.

Section B.1--- Observations of a glider's movement

[NOTE: Place the glider weight back on]

1. Setting up for acceleration of the glider: Place one wooden block underneath the single leg support of the air track. We have elevated the air track so that the glider will be "running" down hill.

2. Putting the glider in motion: Turn on the blower. Release the glider at the beginning of the 120cm distance, i.e. at the elevated end of the air track.

3. Repeat 2 as many times as you need. Complete Part I, Section B.1, of Lab 1 Worksheet.

Section B.2---- Measuring the motion of the glider

4. Setting up to make the measurements: For Table I.B.1 you are asked to find the distance travelled in successive one second intervals. One way of doing this is to have your partner call out each second and then mark, with masking tape, where the front of the glider is at that time. It is helpful to walk along with the glider as you place the tape.

In this way you are looking right out the front of the glider as you place the tape.

It may take several tries to get all the time intervals. Patience, and checking your marks closely, will provide enlightenment about acceleration.

5. Making the measurements: The distances asked for in Table I.B.1 are to be found by measuring between successive pieces of tape, e.g. the distance for interval #2 is found by measuring the distance between the piece of tape put on the track for the first second and the piece of tape put on the track for the second second. Complete Section B.2.

Section C---- A complicated case

Introduction

You will now consider a case where the motion is a bit more difficult than what you have considered this far.

Material

Air track set up (separate system placed on the tables at the back of the room), air track glider, the glider weight with the aluminum fin arrangement, copper shim (to be taped to the aluminum fin), one wooden block (19cm x 19cm x 3.5cm) placed underneath the single leg support of the air track, narrow gap horseshoe magnet (elevated, at a tad past the halfway mark, such that the aluminum/copper fin configuration will pass through the gap of the magnet).

Procedure

You will find the demonstration set up in the back of the room. Turn on the blower. Place the glider on the high end of the air track. Release it. Repeat as many times as you need. Complete Part I, Section C of the worksheet.

Physics Feat: Tips on doing this lab in your classroom

The purchase of an air track for use at the elementary school level is not advised. Most high school science departments have an air track or accessibility to one. Also the high school physics teacher may be able to suggest some alternative experimental set ups. For example the dry ice pucks used in the Project Physics course.[1]

An alternative way of having your students apply the concepts of motion would be to set up a Hot Wheels™[2] track. Let the students play with the toy car and track and then have them analyze the motion.

Part II The Pendulum^2

Purpose

To develop a systematic process of identifying the important parameters involved in the motion of a pendulum (i.e. that period is independent of amplitude and mass, and that period is dependent on length).

Introduction

Whenever an object is hung from a point so that it can swing back and forth it is a pendulum. The pendulum, besides being a reference in macabre literature, is an example of a special type of motion called simple harmonic motion. One example of the use of pendula can be found in a grandfather clock. Understanding how a pendulum works opens the door to understanding musical instruments, lasers, TV, or the design of bridges.

The time for a pendulum to swing across and back to where it started is called its period (T). A good way to measure the period is to determine the time for 10 complete swings and then divide by 10. Thus if it required 30 seconds for 10 complete swings over and back, the period is 3 seconds. The reason we do this is that the average value of the period for ten swings gives a more accurate result than just measuring a single swing (ask yourself why this is so). Work with your lab partner to make this measurement.

The maximum distance the pendulum swings to either side from "straight down" is called the amplitude (A) of the pendulum. The number of complete swings the pendulum makes in one second is called the frequency (f) of the pendulum.

Material

Two 1 meter pendulums (one steel bob, one wood bob), 4 meter pendulum, stop clock, pendulum supports

Procedure

The questions for this part are listed here. Record your observations on the worksheet under Part II.

1. Does the period of a pendulum change as the amplitude changes? See if you can find out. Set up the pendulum with the steel bob. The length, ℓ, of the pendulum should be 1m (ℓ = 1/2 the diameter of the bob + the length of the string from the bottom of the support). Pull it 12 cm to one side and let it go. Measure the period as outlined in the

introduction. Repeat three times. Record your measurements in Table II.1. Now pull the pendulum all the way to one side. Measure the period. Repeat three times. Record your measurements in Table II.2. Answer question II.1.

2. Does the period of a pendulum change when you change the amount of weight on the end of the string? Set up the pendulum with the wood bob per the instructions in step 1. Carry out the necessary measurements to complete Table II.3 and answer question II.2.

3. Does the period of a pendulum change when you change the length of the pendulum? Ask the lab instructor for the 4m pendulum. Your lab instructor will indicate where to set up this pendulum. Be sure to measure the length. Make the appropriate measurements to complete Table II.4 and answer the questions.

Physics Feat: Pendulum Facts[3] (optional)

It is often said that a pendulum has the same period regardless of amplitude. This is not exactly true, as you have helped show. The statement should be: *If* the amplitude of a pendulum is small (for example, less than 10°) then the period is almost constant. Simple harmonic motion is idealized motion in which the amplitude has no effect on the period.

The actual relation from theory for small amplitude is that $T = 2\pi \sqrt{\ell/g}$. Does your data agree with this? How can you show this with a graph?

References

1. Project Physics, Gerald Holton, et.al., Holt, Rinehart, and Winston (New York, 1975).
This text and the support material for the course, provides a good development of physics from a historical and experimental perspective.

2. The Family Science Project, Science Explorations for Children, by Michael E. Browne and Josephine A. Browne. National Science Foundation (Grant SED-7718034, 1979).
The material for Part II was adapted directly from Physical Science Unit 7: The Pendulum. Much of the material is direct quotation.

3. A Survey of Laboratory Physics, Part I, by Paul A. Bender. Star Publishing Company (Belmont, CA, 1985).
The material referenced for this laboratory was taken from Laboratory 2A and Laboratory 4A. Much of the material for Part III was taken in total from Laboratory 2A.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK -- LABORATORY 1

Optional -- A Freely Falling Body*

Introduction

Today you have, through your observations, developed a description of moving bodies which in the language of a physicist is called kinematics. Galileo was the first person to describe motion in this currently accepted manner. He reasoned from experience, starting from the definition of acceleration, using mathematics as the means of deduction. He emphasized the essential role of experiment in testing a physical concept.

Galileo was able to show that:

a.) The acceleration of a body freely falling in a vacuum is constant. This means that during any one interval of time, the gain in velocity will be the same as the gain in velocity during an earlier or later interval of the same length, i.e., $g=$ constant.

b.) The acceleration of a body in free fall in a vacuum is independent of the mass of the body.

In this part of the lab we will check to see if these statements are still true.

Material

Free fall experiment equipment, ruler

The apparatus used to measure the acceleration of gravity is shown in Fig. II.1. The "bomb" which is held at the top of the apparatus by an electro-magnet, is released by opening the switch. It falls freely between a pair of parallel wires. As the bomb falls, a spark jumps from one wire through the flange of the bomb to the other wire every 1/60 second. The spark leaves a small hole in the waxed paper tape. The distance between consecutive holes on the tape is distance the bomb fell during the interval of 1/60 second.

Procedure

1. The lab instructor will aid in obtaining the tapes (one per student).

CAUTION: When starting the sparker, use only one hand, keeping the other in your pocket or behind your back. This will reduce the danger of your becoming part of the circuit and getting shocked.

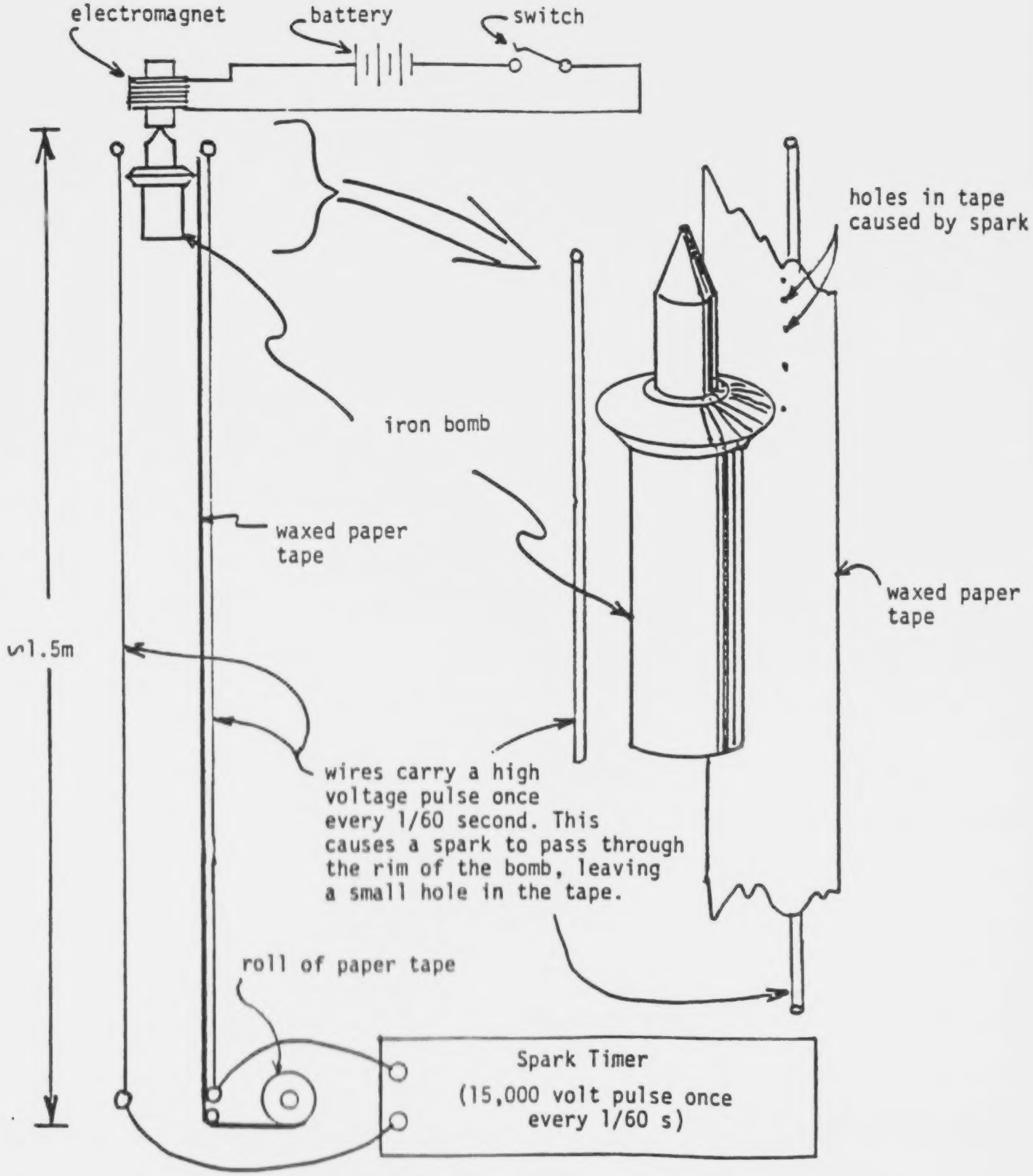

electromagnet
battery
switch
holes in tape caused by spark
iron bomb
waxed paper tape
waxed paper tape
∽1.5m
wires carry a high voltage pulse once every 1/60 second. This causes a spark to pass through the rim of the bomb, leaving a small hole in the tape.
roll of paper tape
Spark Timer
(15,000 volt pulse once every 1/60 s)

Fig. II.1 Apparatus used to measure the acceleration of gravity

2. The exact time of release cannot be recognized on the tape, so pick the second or third dot, circle it and label it "0". See Fig. II.2.

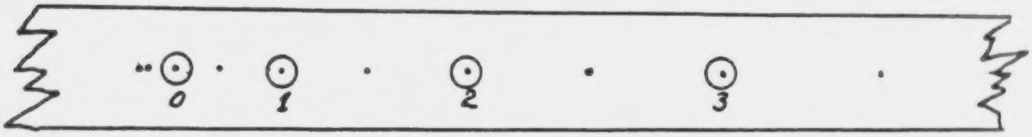


Fig. II.2 A Sample waxed-paper tape record

3. Circle alternate dots and consecutively number the circled dots (using every dot results in too much data).

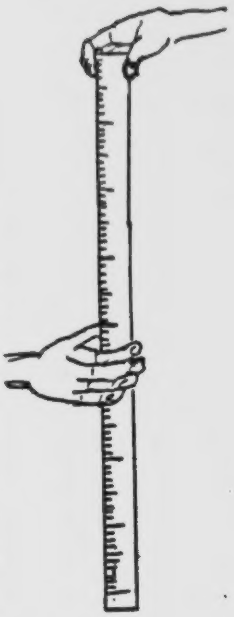
4. Measure the distance (in cm) between consecutively numbered dots and enter the values in Table II.1 of the worksheet. Plot a graph of the distances (on the y axis; distance is the dependent variable) versus time (on the x axis; time is the independent variable). Use the graph paper provided in the worksheet.

5. Plot a graph of the velocities (on the y axis; velocity is the dependent variable) versus time (on the x axis; time is the independent variable). Since each velocity is the average velocity during a 1/30 second interval, plot each velocity at the mid-point of the appropriate time interval. This graph is a test of the statement "a" of Galileo mentioned in the introduction. Use the graph paper provided in the worksheet.

6. From the graph of velocity versus time, find the best value of the acceleration of gravity. The slope of the graph $\Delta v / \Delta t$ (the change in velocity Δv divided by the corresponding time interval Δt) is the acceleration 'g'.

7. Complete the worksheet.

Physics Feat: Measurement of Reaction Time[2] (optional)



One of the characteristics of physics is that knowledge of one aspect of nature may permit measurements of completely unrelated phenomena. For instance, knowledge of the acceleration of gravity can be used to measure the height of a building. One only needs to measure the time for an object to fall to the ground from the roof. One then uses the formula $y= 1/2\ gt^2$ and the value of g to find the height, y.

The measurement of your "reaction time" is made with a falling meterstick. Your partner holds one end of the meterstick and you position your open fingers opposite the 50 cm mark as shown in the figure. Your partner releases the stick at some arbitrary time. The distance it falls before you catch it can be converted into your reaction time using $y= 1/2\ gt^2$. Repeat the measurement several times to get an average. Is there a difference between the reaction time of your two hands?

Repeat this experiment with a dollar bill (with your partner holding one end of the bill and you positioning your fingers at the middle of the bill). You probably will not be able to catch the bill. How does the measurement of your reaction time and the law of falling bodies support this occurrence? Try this one with your betting friends!

Fig. II.3

---

*Adapted from: A Survey of Laboratory Physics, Part 1, by Paul A. Bender, (Star Publishing Company, Belmont, CA, 1985).

Worksheet for
Laboratory 1 -- Optional
A Freely Falling Body

Table II.1

Interval number	Distance traveled during interval D_n	Average velocity during interval $V_n=D_n$ / (1/30 sec)
1		
2		
3		
4		
5		
6		

1. Compare the graph of distance versus time to the graph of velocity versus time. What differences do you see in the shapes of the graphs? What does this suggest about the relationship between acceleration and distance? Acceleration and velocity?

2. Show your work to calculate the value of the acceleration of gravity here. What does the straight line of the velocity versus time graph suggest?

Lab 1 Description of Motion

Apparatus List

Set up is based on 24 students at 12 lab stations

Per lab station

1 ea. 1 ruler
1 ea. Air track set up (rubber band replacing the spring on the support)
1 ea. Timer clock
1 ea. One wooden block (19cm x 19cm x 2cm)
1 Air track glider and glider weight
1 ea. Steel bob pendulum - 1m length
1 ea. Wood bob pendulum - 1m length

Per lab room

Balances
Masking tape
Graph paper tablet
1 ea. 4m pendulum; key to 3rd floor pendulum

Air track set-up on the back demonstration tables (air track glider, the glider weight with the aluminum fin arrangement, copper shim taped to the aluminum fin, one wooden block 19cm x 19cm x 3.5cm placed under the single leg support, close face horseshoe magnet located just past the halfway mark of the air track and elevated such that the aluminum/copper fin configuration will pass through the opening of the magnet).

Worksheets for
Laboratory 1 Description of Motion

Name ______________________ Date ____________
Partner's Name ______________

Part I Motion
Section A.1

1. Describe your observations of the motion of the glider after you release it in terms of distance and time.

2. What inferences can you make about a relationship between distance and time?

Section A.2

Table I.A.1

Interval #	Time of interval (Δt_i)	Total elapsed time at end of the interval Δt_e	Distance traveled over interval Δd_i	Total Dist. traveled by end of interval Δd_e
1	2 sec	2 sec		
2	2 sec	4 sec		
3	2 sec	6 sec		
4	2 sec	8 sec		

3. How do the distances Δd_i traveled during the equal time intervals compare? Does the total distance traveled Δd_e increase at a constant rate?

4. Make the appropriate calculations to complete the following table. Answer the questions following the table.

Table I.A.2

Interval #	Ratio of Δd_i to Δt_i $\Delta d_i / \Delta t_i$	Ratio of Δd_e to Δt_e $\Delta d_e / \Delta t_e$
1		
2		
3		
4		

How do the ratios of Δd_i to Δt_i compare between successive intervals? How do the ratios of Δd_e to Δt_e compare to each other and to the ratios of Δd_i to Δt_i?

5. How long would it take the glider in the case above to travel 200cm using the ratio you found for Δd_e to Δt_e in interval 3. (assume we have an air track long enough)? How far would the glider travel in one minute?

6. In question 5 you used ratios to obtain an answer: given a distance travelled you find a time of travel; given a time of travel you find a distance travelled. Your answers in 5 are predictions based on a ratio of distance to time. List a couple of other examples where you use a ratio of distance to time to make predictions.

7. Sketch a graph of distance (y axis) versus time (x axis). Also sketch a graph of speed (y axis) versus time (x axis). What does the slope of the distance versus time graph tell you? What does the slope of speed versus time graph tell you?

8. Suppose the drawing below represents the position of the glider at successive one second intervals. Did the glider move like the one we investigated in this lab? How do you know?

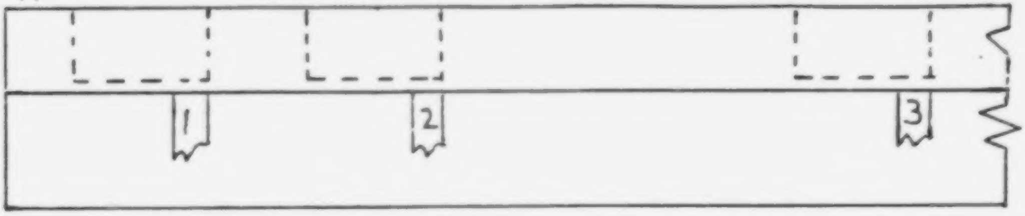


Fig. I.A.1

9. We have now developed the concept of speed----i.e. speed is the ratio of change in distance to change in time ($\Delta x/\Delta t$). This ratio is referred to as the average speed. It is an average since we are not finding the speed at an exact location or at an exact time. Rather we are taking a distance and dividing it over an interval of time, i.e. we are getting "on the average" how far an object goes in one unit of time. This is the information the ratio $\Delta x/\Delta t$ provides. Review your answers to question 1. Record below any changes you would like to make.

Section B.1

1. Record your observations of the motion of the glider after you release it, in terms of distance, time and speed.

2. What inferences can you make about relationships between distance and time; speed and time.

Section B.2

Note: In this part you will be finding an average speed for each interval. Since it is an average speed there is not an exact moment of time that the glider has the speed you find. However, we can estimate that the glider's instantaneous speed at the midpoint of the time it took the glider to travel the interval is the average speed (make sure you can justify this to yourself). For example, if the glider traveled 18cm in a 1.8sec interval, the glider's average speed over the interval would be 10cm/sec; its instantaneous speed at .9sec would be estimated to be 10cm/sec.

Table I.B.1

Interval # and time glider had avg speed	Distance travelled during int.	Average Speed (distance/ 1 sec)
1 t= .5s		
2 t= 1.5s		
3 t= 2.5s		

3. How do the distances traveled during equal time intervals compare? How does this differ from the motion in Section A.2?

4. How do the average speeds in the successive equal time intervals compare? In what way does this differ from what you observed in section A.2? How does this relate to the observed changes in distance?

5. Determine the ratio of the change in average speed (Δv) between successive time midpoints, with respect to the change in time (Δt), i.e. $\Delta v / \Delta t$, to complete Table I.B.2.

Table I.B.2

Time interval of interest	Change in time (Δt)	Change in average speed (Δv)	$\Delta v / \Delta t$
0 to .5s	.5s		
.5s to 1.5s	1 s		
1.5s to 2.5s	1 s		

6. How do the values of $\Delta v / \Delta t$ compare? What does this ratio tell you? We call this ratio the acceleration.

7. What would happen if the change in velocity is negative (as would happen if the glider were to slow down)? Would we still have an acceleration? Why or why not?

8. Sketch the following graphs (the axis assignments are like Section 1 #7): distance versus time, speed versus time, and acceleration versus time. What do these slopes tell you? What relationships do you see between the graphs?

9. We have now developed the concept of acceleration---- i.e. acceleration is the ratio of the change in velocity to the change in time. Review your answer to question 1. Record below any changes you would like to make.

Section C

1. Describe the motion of the glider. Utilize the concepts you have learned in your description.

2. Hand sketch the following graphs: distance versus time, velocity versus time, and acceleration versus time. What relationships do you see between the graphs?

Part II The Pendulum

Table II.1
Period of a pendulum for a small amplitude
length = ____ mass of bob = ____

Trial number	Period
1	
2	

Average =

Table II.2
Period of a pendulum for a large amplitude
length = ____ mass of bob = ____

Trial number	Period
1	
2	

Average =

1. Does the period of the pendulum change as the amplitude changes? Support your answer with your results.

Table II.3
Period of a pendulum for a small amplitude
length = ____ mass = ____

Trial number	Period
1	
2	

Average =

2. Compare the average period of Table II.1 to Table II.3. Does a change in the weight of the pendulum cause a change in the period?

Table II.4
Period of a pendulum with a long length
length = ____ mass = ____

Trial number	Period
1	
2	

Average =

3. How does the average period found on previous page compare to the average value of Table II.1?

4. Based on the investigations you have just completed, what factor is the period most dependent on? Support your conclusion with your results.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 2 The Nature of Force

Purpose

The goal of this laboratory is for you to describe the forces and torques in a physical situation.

Laboratory Objectives

As a result of this session you should be able to:

1. See the force in its role of push-pull
2. Contrast force and the "net-force"
3. Distinguish force on an object from those by that object
4. Determine the magnitude and direction of torque for simple cases.
5. Identify the physical concepts of this lab as they apply to push-pull wagons, trikes, bikes, teeter-totters, etc.

Part I Static Forces and Torques

Section A---- Finding the balance of force

Introduction

Net Force

When a group of forces, all of which pass through the same point, act on an object, they may be replaced by a single force called the net force (F_{net}) or resultant. The magnitude and direction of this net force (F_{net}) may be determined by drawing the proper vector force diagram, as was discussed in the lecture.

Equilibrium --- Net Force of Zero

In this section of the laboratory you will be working with the case when the net force is zero (i.e. the vector sum of all the forces is zero). This is referred to as the first condition of equilibrium. We will discuss the second condition in Section B.

An object is in equilibrium when the conditions are present for the object to have zero acceleration. Knowing that $F_{net} = ma$, it is apparent that if the net force is zero, the acceleration must be zero! So, it follows that a net force of zero is a condition for equilibrium.

We can now refine our definition of equilibrium using our knowledge of motion from laboratory one, to be.

> Equilibrium is the condition of an object whose velocity is constant in magnitude and direction.

In this part of the laboratory you will consider the case where velocity is the constant zero. This is called static equilibrium. The case where the object remains in steady motion in a straight line is called dynamic equilibrium.

EXPERIMENT-----A car on an inclined plane

Introduction

You will determine the net force on a car sitting on an inclined plane. You will need to make a vector diagram to determine what must be done to achieve a net force of zero. Using pulleys and weights you will apply the forces required to give a net force of zero without the plane present.

NOTE: You are asked to determine a force identified as F_n (read F sub n). It is the force of support due to the board and in the absence of friction it is perpendicular to the plane. F_n is often called the "normal force", where normal refers to the force being perpendicular to the board's surface. To determine F_n you need to recognize that the net force in the y direction is zero. [This follows since the car is neither flying off of or sinking into the board!]. Knowing that the sum of the forces in the y direction add up to zero, you can find F_n.

Apparatus

Car on an inclined plane set-up, 30-60-90 triangle, ruler

Procedure

1. Refer to Figure I.1. Carry out the appropriate work to determine the vector component of the car's weight along the plane (W_x) and the vector component of the car's weight perpendicular to the plane (W_y). Show your work on the worksheet.

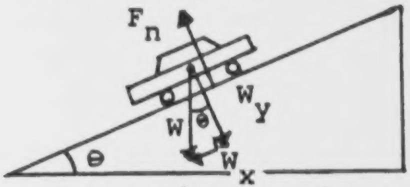


Fig. I.1 Force Diagram of car on plane

2. Determine the force you need to apply to give a net force of zero. Use a pulley and weights to apply this force.

3. Complete the worksheet for this section.

Section B---- Finding the balance of torque

Introduction[1]

What is torque?

A force's tendency to produce rotation of a body is called the torque. It is equal to the product of the force's magnitude times the perpendicular distance from the axis of rotation (a fulcrum, if you like) to the force's location. This is illustrated in Figure 2. Here a force F is shown applied to a wrench at a point P a distance $R_\perp$ away from the center of the nut. The magnitude of the torque is $FR_\perp$. The distance $R_\perp$ is called the lever arm of the force F about the nut's center.

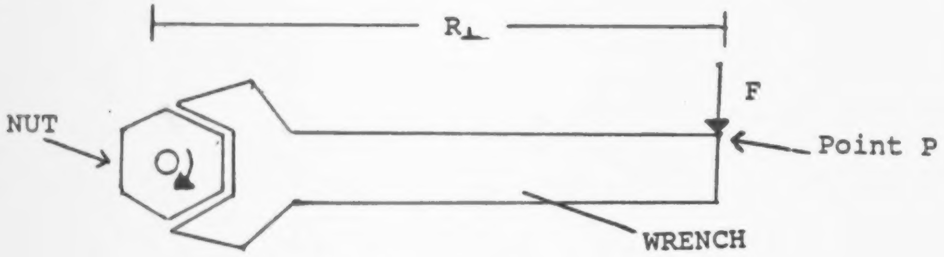


Fig. I.2 The Torque

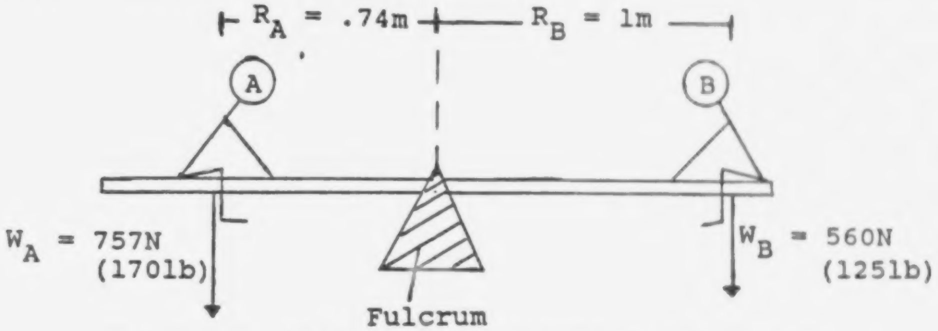
If we had applied the force in the opposite direction we would have had the same magnitude of torque, but a different direction of rotation. We identify the torque vector with both its magnitude and the direction of rotation it causes. So in Figure 2 the torque is $FR_\perp$ in a clockwise (CW) direction. If the force had been from the opposite direction the torque would have been $FR_\perp$ in a counter clockwise direction (CCW).

Equilibrium --- Net torque of zero

Based on the definition of static equilibrium, we can see that a net torque of zero is also required for equilibrium. If the net torque is not zero, as with the wrench in

Figure 2, we get a rotation. Hence, we do not satisfy our definition of static equilibrium, i.e. a constant velocity of zero.

As an illustration of how to use net torque, we consider the situation shows in Figure 3.



W_A and W_B indicate the weights of A and B

Figure 3 Teeter-Totter

To find the net torque we need to add the torque due to A to the torque due to B. First we will find the magnitudes and directions of each;

$$T_{\text{due to A}} = W_A R_A = (757\text{N})(.74\text{m}) = 560 \text{ N m}$$ counterclockwise

$$T_{\text{due to B}} = W_B R_B = (560\text{N})(1\text{m}) = 560 \text{ N m}$$ clockwise.

If we add the two torques, we see they cancel since they oppose each other. Therefore, this is a case of net torque equal to zero.

Notice, we can use this relationship to find an unknown value of weight or length. You will do this in lab.

Conditions of Equilibrium

To summarize, the conditions of equilibrium are:

Condition 1 - The net force [sum of all forces] acting on the object must equal zero. (Otherwise the body would accelerate in the direction of the net force.)

Condition 2 - The net torque [sum of all torques] acting on the object must equal zero. (Otherwise the body would rotate at ever decreasing and increasing speeds.)

You will apply these condition in the worksheet.

EXPERIMENT-----Torque

1. Finding your partner's weight.

    a. Arrange the large plank on its fulcrum, so that it is balanced as well as possible. This is to balance out the torque due to the weight of the board. The net torque due to the board should now be zero.

    b. Convert your weight from pounds into Newtons. The conversion factor is 4.45 Newtons = 1 pound.

    c. Knowing your weight in Newtons, devise an experiment using the 'teeter-totter' to determine your partner's weight.

    d. Show your work on the worksheet, Part 1 Section B.2. Answer the questions in this section.

2. T-Stick

    a. Experiment with the green wooden T-shaped device. Use the weight hanger to hold different weights at different distances from the handle.

    b. Summarize your observations on the worksheet.

Part II Dynamic Forces

Section A---- Newton's laws in reaction[3]

Introduction

In this part of the lab you will investigate Newton's third law. For every force (action) on A due to B there is an equal and opposite force (reaction) on B due to A. A simple translation of this is: If you push on something, it will push back on you just as hard. If you pull on something, it will pull back on you just as hard.

Apparatus

2 skateboard platforms, 18 feet of cord

Procedure

1. Partner up with someone about your size. Place the skate boards about two or three meters apart. Be sure they lie along a straight line pointing at each other.

2. You and your partner should stand on the skateboards facing each other. Have your partner tie one end of the cord around his/her waist. You pull on the other end. Record your observations on the worksheet.

3. Now tie one end of the rope around your waist and let your partner pull on the rope. Record your observations on the worksheet.

4. Now both of you pull on the rope. Record your observations on the worksheet.

5. Bring the skateboards together. Have your partner push off of you. Repeat with you pushing off of your partner and also with both of you pushing off each other. Record your observations on the worksheet.

6. Repeat steps 1 through 5 with someone larger than you, (ideally twice the size).

7. Complete the worksheet.

OPTIONAL----

Section B---- Measurement of the acceleration of the elevator[2]

Introduction

To make this measurement you will measure the force produced by the acceleration of the elevator on your own mass.

Apparatus

Elevator (>6 floor run), bathroom scale

Procedure

1. Measure your weight in pounds with one of the bathroom scales. These scales are not very accurate, but use the reading to find your weight in newtons. The conversion factor is 4.45N/1 lb. Now calculate your mass in kilograms.

2. Take the bathroom scale and your partner onto the elevator. Stand quietly on the scale as your partner records the scale reading for at least the following; the maximum weight, the minimum weight, and the weight during the middle part of a long run (>6 floors). Note the conditions under which each of these occurs (elevator going up or down, beginning or end of ride between floors).

3. Sketch a graph of apparent weight (vertical axis) vs. time (horizontal axis) for a typical long run up, and another graph for a long run down. Staple this to the worksheet.

4. The acceleration is calculated from the following formula;

$$W' = W_o + Ma$$

in which; W' is the apparent maximum (or minimum) weight, (as read from the scale) W_o is the weight (as measured in the lab before getting on the elevator) M is the mass (as calculated in part 1) a is the acceleration. The acceleration will turn out to be positive when the speed of the elevator increases while moving upward or decreases while moving downward. The acceleration will be negative when the speed decreases upward or increases downward.

This equation is an expression of the net force. It comes from;

$$F_{net} = ma = W - W_o.$$

5. Answer the questions on the worksheet.

References

1. Experiments in College Physics, 6th Edition, by Benard Cioffari and Dean S. Edmonds, Jr. D.C. Heath and Company (Lexington, Mass, 1978).
The material used in this lab was taken directly from Laboratory 2 - Addition of vectors. Equilibrium of a Particle. (pg. 11 - 14) and Laboratory 3 - Equilibrium of a Rigid Body (pg 15).

2. A Survey of Laboratory Physics, Part 1, by Paul A. Bender. Star Publishing Company (Belmont, CA, 1985). The material referenced for this laboratory was taken from Laboratory 3A in total.

3. The Family Science Project, Science Exploration for Children, by Michael E. Browne and Josephine A. Browne. National Science Foundation (Grant SED-7718034, 1979). The material for Part II Section A was adapted directly from Physical Science Unit 1: Force and Motion. Questions 6, 7, 8 worksheet come from here.

Worksheets for
Laboratory 2 The Nature of Force

Name____________________________________ Date____________

Partner's Name__________________________

Part I Static forces and torques

Section A.

1. Make a sketch like Fig. I.4. Scale the force diagram to determine the components of W (use the procedure outlined in the lecture and your laboratory instructors introduction). Record your values in the appropriate blanks.

Magnitude of the forces

W = ______________ W_x = ______________

W_y = ______________ F_n = ______________

2. What is the magnitude and direction of the force required to give the car, when it is on the plane, a net force of zero? If the car has a net force of zero when it is set up on the plane which way will it move? Test your answer by setting the car up on the plane with the force you have determined with string, pulley, and weights.

3. Replace the normal force (F_n) with another string, pulley, and weights and then pull out the plane. What happened when you pulled the plane out? Why? [Use the concept of equilibrium in your explanation.]

4. Move the car - what happens. Why?

5. Draw a force diagram (not to scale) of the forces acting on (a) the inclined plane and (b) the car. In addition to the direction of the force vectors, also indicate magnitudes.

6. Explain clearly the source of the forces you drew in 5a and 5b. Be concise.

Section B

Teeter-totter

1. Sketch your experimental set-up here. Indicate distances, forces, and torques. Explain, briefly how the set-up meets the conditions of equilibrium.

2. Show your calculations to determine your partner's weight, in Newtons.

T-Stick

1. Observations

2. Do your observations support our definition of torque?

Part II

Section A.

1. Record your observations for procedure #2, #3, and #4 below. Identify each part.

2. Observations for procedure #5.

3. Record your observations for #6 below. Identify each part.

4. Summarize Newton's third law based on your observations.

5. How was Newton's second law illustrated by doing the experiment with a person your size, and then with someone larger (or smaller) than you.

6. Can something exert a force if it is not moving? How?

7. You learned that when you push on something it pushes back on you. Using this, explain how you are able to walk.

8. What happens if you are in a canoe and try to jump out onto a dock? Answer this in terms of Newton's laws of motion.

OPTIONAL

Section B

1. Calculate the maximum positive acceleration and the maximum negative acceleration in units of m/s^2.

2. If the elevator were in free fall what would your apparent weight be? What would be your acceleration?

Lab 2 Nature of Force

Apparatus List

Per Lab Station

1 ea.	inclined plane device
1 ea.	car with eyehooks (thumbtacks on dowels) (preweighed)
2 ea.	50g. weight hangers
2 ea.	weight sets (on rider)
2 ea.	table clamps
2 ea.	rod uprights
2 ea.	rod clamps
2 ea.	pulleys on rod supports
1 ea.	30-60-90 triangle
1 ea.	ruler
1 ea.	green handled
1 ea.	weight hanger
1 ea.	1/2 kg, 1 kg, 2 kg weights

Per Lab

1 ea.	ball of string
4 ea.	bathroom scales
1 ea.	scissors
4 ea.	skateboard platforms
2 ea.	cord - 3 meters long
2 ea.	large plank
2 ea.	dowel rod support

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 3 Work and Energy

Section A.1 -- Levers

Purpose

The goal of this laboratory is for you to understand the mechanical advantages of simple machines, the concept of work as used in physics.

Laboratory Objectives

As a result of this session you will:

1. Distinguish between force and energy
2. Recognize energy in its different forms
3. See the applications of simple machines as force redirectors, magnifiers, and reducers.

Introduction

In this section of the lab you will determine the mechanical advantage of various levers and describe how the forces work with the levers.

Apparatus

Lever demonstration (metal bar, saw horse, and blue motor), human lever display (back, ankle, bicep, and the tricep), exposed watch, nutcracker and nuts, hand drill, large plank and fulcrum, a door handle with detachable knob, screwdriver and paint can with lid, broom

Procedure

1. The lab instructor will indicate the location of the lever station.

2. Complete the worksheet for this section.

Section A.2 -- Inclined Planes and Screws

Introduction

In this section of the lab you will determine the I.M.A. and A.M.A. for an inclined plane. You will also show that a screw is simply an inclined plane wrapped around a cylinder.

Apparatus

Plank used in 101 labs (mount to the table 80cm from its end), large protractor, plumb-bob, screw demonstration from lecture demo, suitcase loaded with 10kg of mass, 15kg spring scale, screw demonstration from Lecture Prep, lipstick container (with screw bottom).

Procedure

1. Your lab instructor will indicate the inclined plane station.
2. Determine the weight of the suitcase, the length of the board (to where it rests on the table), the height the board is above the floor (measure it to where the board meets the table), and the angle of the board. Record these values on the worksheet.
3. Complete the worksheet questions on the inclined plane.
4. Complete the worksheet questions on the screw.

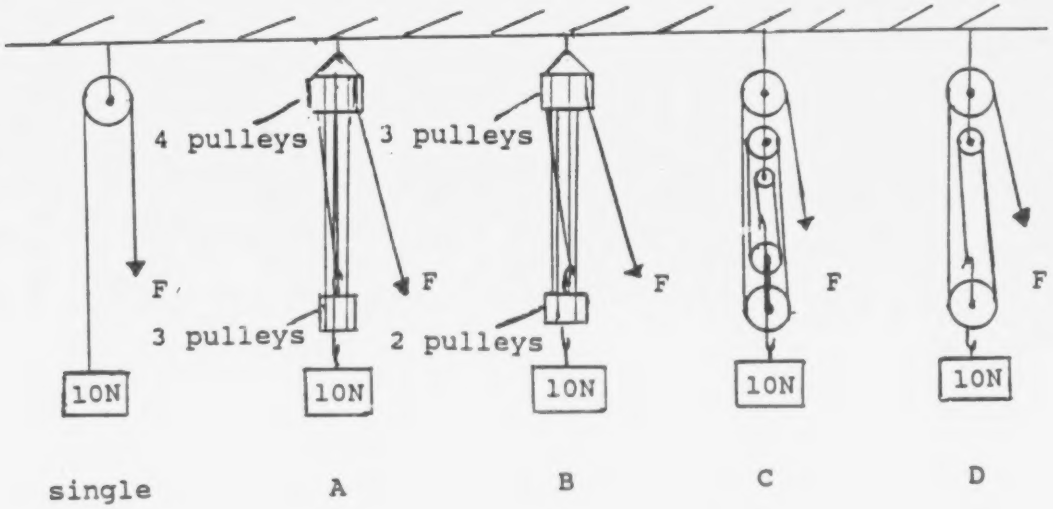
Section A.3 -- Pulleys

Introduction

In this part of the lab you will determine the I.M.A. and A.M.A. of different pulley systems.

Apparatus

(2x)4 pulley set-ups shown in Fig. A.3.1 below (8 all together) hung from the ceiling, string (nylon cord), step ladder, 8-2000g spring scale, 8 eye bolts (in place in the overhead runner), 8 1000g hooked weights, 3 single pulleys.


4 pulleys
3 pulleys
F
F
F
F
F
3 pulleys
2 pulleys
10N
10N
10N
10N
10N
single
A
B
C
D

Pulley Set-ups
Fig. A.3.1

Procedure

1. Your lab instructor will indicate the location of the pulley station.

2. With the spring scale measure the force required to lift up a load of 10N(1000g) with the single pulley set-up. Lift with a slow uniform speed. Raise the load .20m. Measure the distance the applied force must act through. Record your observations on Table A.1.

3. Repeat the process with the pulley set-up designated by your instructor. Do not enter these values into the table. Enter your values on the table drawn on the chalkboard.

4. Average the values for each pulley set-up. Record these in Table I.A.1.

5. Answer the questions on the worksheet.

Work

Introduction

As was discussed in the preceding section, in physics the word "work" means a force acting through a distance and is given by the product of that force and the distance through which it acts (W = F x D). Also it was mentioned that the units of work are joules or foot-pounds. You should keep in mind that this distance does not have to be along a straight line, it could also be the distance a wheel turns around. The quantity of work tells us how much energy we need or have used to accomplish a task.

Another measurement that is quite useful in physics and industry is how fast work is being accomplished or being done. This quantity, the rate of doing work, or the work per unit time -- is called POWER.[1] Average power is found by the following equation:

$$P = W / t$$

where P = power, or how quickly you are doing work (using up energy,
W = total work done,
t = time during which work is done (expressed in seconds).

The units of work are foot pounds or Joules per second (J/s), or more commonly called Watts. You have probably heard of kilowatt hours in connection with electrical bills. This simply tells you how much work was consumed during the billing period (or, if you like, the amount of energy used during the time since the last bill). If you look on a light bulb, toaster, iron, or just about any household appliance you will find a power rating. A light bulb, for example, may have a value of 60W (60 Watts) painted on top. This value tells you it takes 60 Joules of work a second to produce the light you use to see with. Much of this work goes to heat (feel the bulb).

In this part of the lab you will be the producer of energy for the work required to power a headlight or two. You will accomplish this task by pumping a bicycle to provide the work necessary to operate a car generator. The generator will then produce electrical energy which will be used to provide the work required to make the light bulb glow. From the work you do you should gain a feeling of how much work we expect the electric company to provide us.

Apparatus

Bike generator set-up

Procedure

1. Your lab instructor will indicate the location of the generator apparatus.
2. When it is your turn to use the generator, take time to look at how the set-up utilizes simple machines to transfer the work caused by the flexing of your muscles to the work required to light the light. Be sure to consider the levers in your legs as well. Summarize briefly on the worksheet.
3. Pump on the bike until you get the light or lights to glow. The power you are producing at that point can be found by multiplying current and voltage (the units will be in Watts). This is equivalent to W/t. Complete the worksheet for this section.

Optional Activities

1. Examine the exposed watch. Briefly describe (in words and drawings) how the stem transfers your applied force into stored energy in the spring.
2. Examine the doorknob. What advantage does the knob have over the spindle? Explain in terms of lever arms and torques.
3. Examine the human lever demonstrations. Make the necessary measurements to estimate the ideal and actual mechanical advantage of the bicep. How does this compare to a simple lever? What class of lever is this set-up? What is the efficiency of this system?
4. Calculate the efficiency for a pulley, lever, and ramp system.
5. Determine the AMA for the pulley system below.

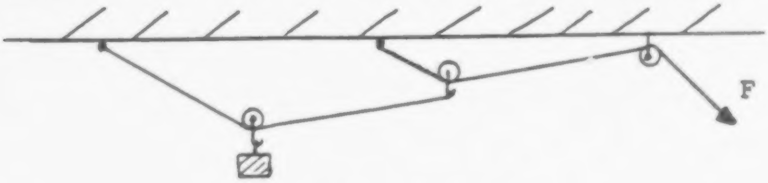


Fig. A.3.2.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 3 Work and Energy

Simple Machines

Introduction to simple machines[1,2]

How are screwdrivers, hearts, eggbeaters, and automobiles alike? They are all machines. To talk about machines we need to understand the following:

A FORCE is a push or pull as you discovered in Laboratory 2.

> When you push or pull something (apply a force) and make it move you do WORK on it. Work is done in the distance a force moves something. It is given by WORK = FORCE X DISTANCE (Force in newtons, distance in meters); the unit of work is the Newton-meter which is given the name Joule.

It requires ENERGY to do work. Energy is the ability to do work or to change the state of matter; it is also measured in Joules.

A Simple Machine is a Force Magnifier (or reducer) which is used to change the magnitude or direction of a Force so that it can be used more conveniently. A Compound Machine is a combination of simple machines.

Basically a machine can do the following:

A machine can change a small force into a large one (magnifies the force).
A machine can make things move faster.
A machine can change the direction of a force.
Machines can make it easier to do work.

Note that you must put energy into the machine in order to get it to do work. A machine cannot make energy.

Machines are not to be confused with:

> Engines which convert thermal energy to work or convert chemical or nuclear energy to thermal energy and then to work.
>
> Motors which convert electrical energy to work.

Today we are going to study some special simple machines: the lever, the inclined plane, the screw, and the pulley. Each of these has been used for centuries; complex machines are just clever combinations of these.

Levers [1,2]

An example of a simple lever is shown in Fig. 1. F is the applied force (the force you apply to the lever); L is the load force -- the force which is available at the output end of the machine as it is operated (for example it is the amount of force [or weight if you like] you could lift at the end of the lever); P is the fulcrum; D_F is the distance from the applied force to the fulcrum (it is called the lever arm to the applied force); and D_L is the distance of the load force from the fulcrum (it is called the lever arm to the load force).

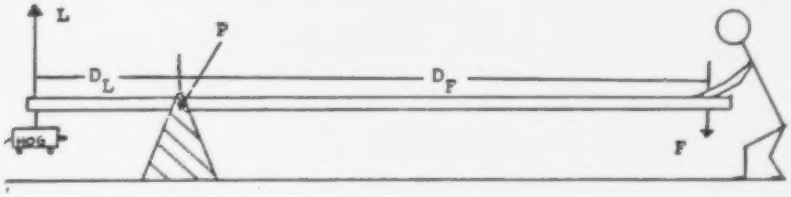


Figure 1. A Simple Lever (First Class)

Note that the lever arm, as in any type of lever, is the perpendicular distance from the fulcrum to the force, whether it be the applied force or load force. This is the same method we used to calculate the torque in Laboratory 2. A lever takes advantage of the torque created by the force. You can calculate the output force by using the methods you developed in Laboratory 2. The type of lever, shown in Fig. 1, is sometimes called a first class lever (the fulcrum is between the applied force and the load force).

A pair of scissors, shown in Fig. 2, illustrates another use of the first class lever. If one blade of the scissors is regarded as fixed, then the force F applied by the user results in a force L being developed by the blade of the scissors against the material being cut. P is the pivot around which the blade turns. Other examples of this type of lever are a screwdriver used to pry a lid off of a can, a teeter-totter, the mounting of a diving board and a hammer being used to pry a board.

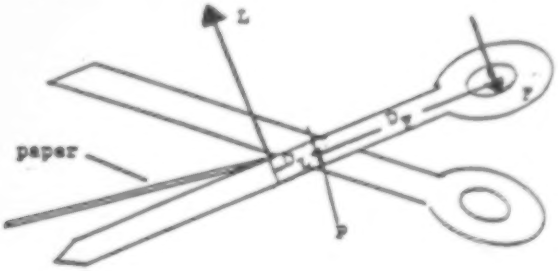


Figure 2. Scissors in terms of Simple Machines

Another type of lever is the second class lever. In a second class lever the load force is between the applied force and the fulcrum. Fig. 3 shows an example of this type of lever. Here the applied force F results in the lifting force L on the load. The axle of the wheel acts as the fulcrum. A nutcracker is another example of this type of lever.

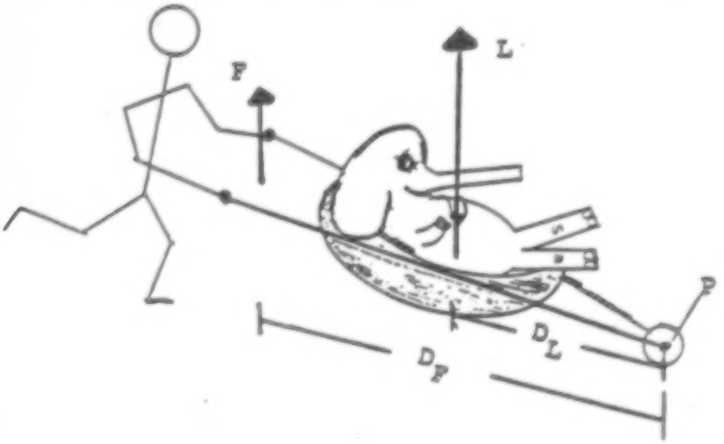


Figure 3. A Second Class Lever

A third type of lever is the third class lever. Here the applied force is between the fulcrum and the load force. An example is shown in Fig. 4. The applied force F, shown in Fig. 4, results in the lifting force L on the textbook, with the elbow joint acting as the fulcrum. Another example is when you use a broom in sweeping.

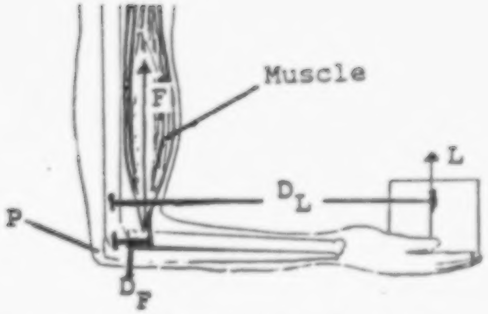


Figure 4. A Third Class Lever

A fourth type of lever is the wheel and axle. Looking at Fig. 5, a force F applied at the rim of one of the wheels tends to turn the whole set-up and thereby causes a load force L to develop on the rim of the other wheel. In this manner you can see that it is just like any other lever. An eggbeater also illustrates this.

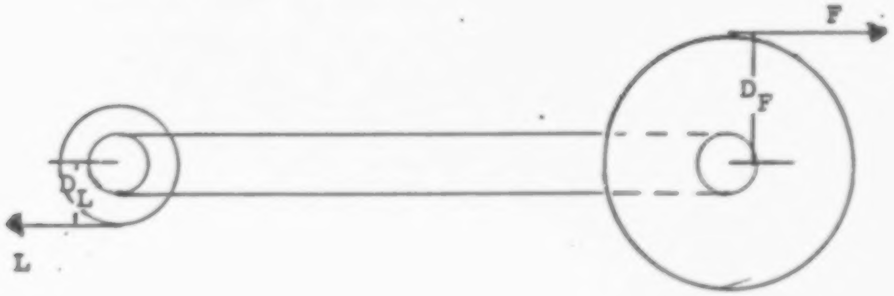


Figure 5. The Wheel and Axle

Another illustration of the wheel and axle is shown in Figure 6, where gear teeth serve to connect the two wheels, and Figure 7, where a chain connects the two wheels. The gear teeth, belt, or chain serve to transmit the force from one wheel to another. Each wheel acts like a lever, where the radius of the wheel acts as the lever arm.

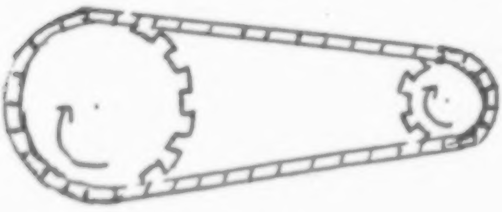


Figure 6.
Gear Teeth

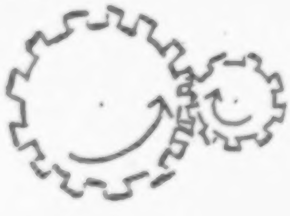


Figure 7.
Chain connecting
Gears

Inclined Plane and Screws[2,3]

An inclined plane (or more simply a ramp), is used to make it easier to lift a heavy load. The principle of how an inclined plane accomplishes this is shown in Fig. 8., which represents a sloping board on which a box is being pulled up the board. W is equal to the weight of the box (mg, it points straight down); W_x is the component of the box's weight along the ramp (it points down the ramp); F_N is the force perpendicular to the ramp and pointing up from the plane (it is the force the ramp applies to the car); F is the force applied to move the box up the ramp (Note that we have ignored friction. If it were included it would point in the same direction as W_x, since friction forces oppose the motion).

As can be shown through graphical vector addition (see Laboratory 2). W_x is less than W. Therefore you can see that it takes less force to pull (or push) a box up a ramp than to lift it straight up!

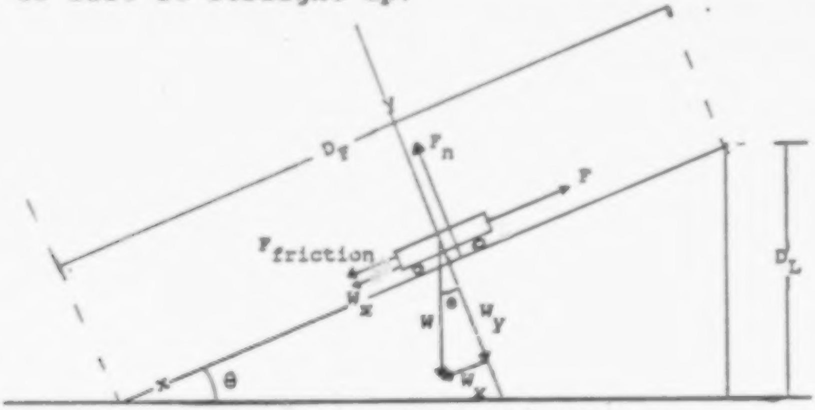


Figure 8. An Inclined Plane

A wedge, an ax, and a knife blade are other examples of the inclined plane simple machine.

An ordinary screw is an inclined plane wrapped around a cylinder (see Fig. 9). The upper edge of the inclined plane follows a helical path which forms the screw thread. The inclined plane in this form is used in almost all machinery built for home or industrial use.

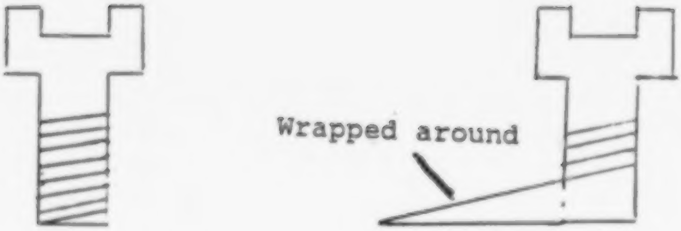


Figure 9. Relation between a screw and ramp

Pulleys[1,2,3]

A pulley is a wheel which can be used to change the direction of a force. A simple pulley is illustrated in Fig. 10. The pulley is attached to a support; the rope is tied to the load and then passed over top the pulley; the person applies a force, F, to the free end. This results in an upward force L on the attached end of the rope. In the absence of friction in the pulleys, the tension in the rope is the applied force F.

If the load in Fig. 10 is being lifted, such that its net force is zero, the applied force, F, must equal the load force, L. So if the load equals 670N, then the applied force will also equal 670N. In practice the applied force is greater than the load force due to friction in the pulley. Notice that should we pull the load 20cm into the air we will have to pull the string 20cm.

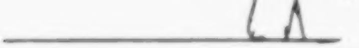


Figure 10. A pulley

A combination of pulleys not only change the direction of the force, but also reduces the magnitude of the applied force needed to lift a load. Consider the pulley system shown in Fig. 11. The applied force is F. The load force L is pulled on by three strands of rope: two by means of the pulley that is attached to the load and one that is attached to the load directly through the pulley; in effect each strand of the rope is supporting one third of the load (L/3). This means that our applied force F will be equal to one third the load force (L/3).

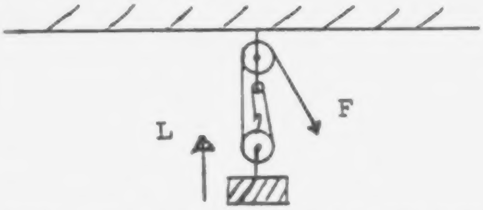


Figure 11. A system of pulleys

If there is friction in the pulleys, a force larger than L/3 must be exerted on the rope. However in both the friction and non-friction case, lifting the load through 10cm requires that each strand be shortened by 10cm, which means that 30cm must be pulled out of the pulley system. So the force must be moved through a distance three times that which the load is raised.

Characteristics of Simple Machines[1]

We will now investigate several characteristics of simple machines by which we can judge their behavior.

Efficiency

As you have gathered from reading about the various machines, the applied force F must move through a distance and therefore does work; this input of work represents the energy supplied to the machine from an outside source. But during this process the load force L also moves through a certain distance, and does work -- an output of work or energy. It is this output of energy which may be usefully utilized.

The efficiency of any machine is defined to be the ratio between the output of work from the machine and the input of work to the machine:

$$E = \frac{\text{work out}}{\text{work in}} = \frac{L(D_L)}{F(D_F)}$$

Where E = Efficiency of a machine.
L = load force exerted by the machine.
D_L = distance moved by load force L.
F = force applied to the machine.
D_F = distance moved by the applied force F.

This ratio is often expressed in percent (by multiplying by 100); it can be thought of as indicating the fraction (or percentage) of the total energy put into the machine which appears as usable energy at the output end of the machine. For an ideal machine we would have no friction and therefore the efficiency would be 1 (or if you like 100%).

With any real machine we have friction forces. Since these forces will be present whenever we put work into the system it is evident that the output work will be less than the input work. The work done by the applied force must provide the work to move the load in addition to work done by the frictional forces. Often this friction is useful! For example when you lift a heavy load up with a pulley, friction helps keep it from falling back.

So, in the real world the efficiency will always be less than 1 (or 100%). In this lab you will determine the efficiency of the different simple machines.

Mechanical Advantages[3]

Since we get less energy out of a simple machine than we put in, you might ask why we even use them. The following example will illustrate the advantage of simple machines. Suppose we wish to change the tire on a 9000N (~2000 lb.)car. The work required to raise it .20m is 1800J (i.e. Work = Fd). Most people cannot do this directly!

If, however, we use a jack, we can easily develop the 9000N force and raise the car .20m. The person accomplishes this by applying a force of, say 225N at the jack handle, the jack multiplying this force by 40, assuming no friction. But the person operating the jack has to pump the handle up and down many times. By the time the car is raised .20m, the handle will have been pushed through a total distance of .2m x 40 = 8m. The work of 8m x 225N = 1800J at the input is felt as (.20m) x 9000 = 1800J at the output. Note how the proportion of force and distance has been drastically altered.

It is apparent that a small amount of force moving through a large distance can accomplish the same amount of work as a large force moving through a small distance. This is illustrated by the jack. This work relation explains how simple machines can help with tasks. The ratio of the applied force to the load force in a simple machine is called its mechanical advantage. This ratio, in effect, tells you how much a machine magnifies the force you apply, i.e. the advantage you get.

In the previous example, ignoring frictional losses, the ratio for mechanical advantage is the same as the ratio of the distance moved by the input force to the distance moved by the output force. This is true for any simple machine (try verifying this for yourself).

In any actual machine, however, frictional losses do exist and must be supplied through additional work by the applied force. So, in the jack, frictional forces in its mechanism might require a force of 300N rather than the 225N exerted on the handle to develop the 9000N load force. The actual mechanical advantage (A.M.A.) is then only 9000N/300N, or 30 instead of 40. The handle must nevertheless be pumped through the same 8m to raise the car .20m as before.

So the mechanical advantage the jack would have, under the ideal conditions of no friction, remains the ratio of the total distance the car is raised: 8m/.20m or 40. This is called the ideal mechanical advantage (I.M.A.) and is given for any simple machine by the ratio of the distance moved by the applied force to the distance moved by the load force.

Therefore the two equations we have to describe mechanical advantage are:

$$\text{I.M.A.} = \frac{D_F \text{ (Distance moved by applied force)}}{D_L \text{ (distance moved by load force)}}$$

$$\text{A.M.A.} = \frac{L \text{ (Load force)}}{F \text{ (Applied force)}}$$

The distances, D_F and D_L that are shown in the figures of this writeup are the ones to be used in the I.M.A. equation.

In the lever shown in Fig. 1 the distances moved are proportional to D_F and D_L, respectively; thus in this case I.M.A. is equal to D_F/D_L. A large lever arm D_F means a large I.M.A., which follows from experience with levers and torques in Laboratory 2.[*] The height of the upper end of the inclined plane (ramp) of Fig. 8 represents the distance D_L through which the load is lifted when the applied force moves the entire length of the plane (D_F). Hence, a long gently sloping ramp would have a very high I.M.A.

A convenient way to determine the I.M.A. of a system of pulleys, such as shown in Fig. 11, is to count the number of strands supporting the moveable pulley. Analysis of the operation will show that this gives the I.M.A. directly. For other pulley arrangements one must inspect the pattern and see how far the applied force F must move in order to move L one unit of distance.

Keep in mind that I.M.A. is the ideal case with no friction. Any practical machine will have an A.M.A. less than I.M.A.

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*Even though the lever arm is not the distance the force moves through, it is proportional to that distance. This can be shown from similar triangles, drawn from distances of movement and lever arm distances.

References

1. Brief Course in Physics, by Lester T. Earls. Kendall/Hunt Publishing Company (Debuque, Iowa, 1968). Excellent book! Has many household physics laboratories.

2. The Family Science Project, Science Exploration for Children, by Michael E. Browne and Josephine Browne. National Science Foundation (Grant SED-7718034, 1979).

3. Experiments in College Physics, 6th Edition, by Bernard Cioffari and Dean S. Edmonds, Jr. D. C. Heath and Company (Lexington, Mass., 1978).

Worksheets for
Laboratory 3 Work and Energy

Name ______________________________ Date ____________

Partner's Name ____________________

Part I Simple Machines

Section A.1 -- Levers

Motor Lifting Lever Set-up

1. Record the weight of the Blue Motor ___________________
   (Convert to Newtons)

2. What class of lever does this set-up illustrate? ________

3. Try the lever set-up at the three different lever arm lengths marked on the bar. Below, sketch each case, indicating the lever arm length to the applied and load force.

4. Which of the above situations was it easiest to lift the motor? Why? Explain in terms of torques, and lever arms. Calculate the applied force for this case.

5. Make the necessary measurements to determine the ideal mechanical advantage of the case that was easiest to lift the motor and that that was most difficult. How do the numbers compare? Why might this be?

6. Explain what mechanical advantage means, based upon your observations, prelab reading, and calculations. How does mechanical advantage convey the idea of force magnification or reduction?

Miscellaneous Levers

Experiment with the rest of the equipment. Answer the questions below.

1.a. Sketch the screwdriver and lid indicating the fulcrum and lever arms.

b. What class of lever does this set-up illustrate?

2.a. Sketch the nutcracker with a nut, indicating fulcrum and lever arms.

b. What is the ideal mechanical advantage of this system?

c. What class of lever does this set-up illustrate?

3. Hold the broom as shown in Fig. I.A.1. The hand at the top of the broom is the location of the fulcrum and is held fixed. The hand on the handle is used to supply the applied force which moves the broom.

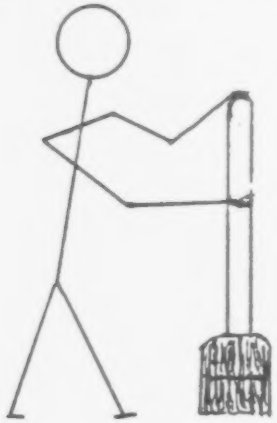


Fig. I.A.1
The Broom

a. Indicate, on Fig. I.A.1, the fulcrum and lever arms.

b. What class of lever does this set-up illustrate?

c. What is the ideal mechanical advantage of the broom determined from measurements made while you hold the broom.

d. How does the distance your hand (holding the handle) moves compare to the distance the end of the broom moves?

5. Examine the hand drill.

a. Briefly describe (in words and drawings) how the direction of force is redirected. (i.e. which turns faster, do all wheels turn in the same direction?) and how the force is magnified or reduced.

b. What class of lever does this set-up illustrate?

Summary

1. In your own words, describe (with examples from your laboratory experiences) how levers demonstrate the ability to magnify, reduce, and redirect an applied force.

Section A.2 -- Inclined Planes and Screws

Inclined Plane

1. Weight of suitcase (in Newtons) ____________________

   Length of board ________________

   Height of board above floor ________________

   Angle of board _______________

2. Lift the suitcase onto the table using the spring scale. Record the average spring scale value ____________.

3. Pull the suitcase up the ramp using the spring scale the height of the table. Record the average spring scale value ______________.

4. What do your values suggest? What is the easiest way (in terms of force applied) to lift this suitcase to the table?

5. How does this machine accomplish its task? (i.e., does it magnify, reduce, or redirect a force?) Draw on your experiences in Laboratory 2 to develop an explanation.

6. Calculate the work done for lifting and for pulling. How do these compare? Does this agree with what you know about simple machines? Why or why not?

7. Determine the I.M.A. and A.M.A. of the board. Are they the same or different? Why? Show your work below.

8. If you were to decrease the angle of the board how would the I.M.A. change? The amount of work done?

The Screw

1. Unroll the large screw model. Explain in your own words how a screw is made from a wound up ramp.

2. Take apart the lipstick container. How does the amount you turn the base of the container relate to the amount the lipstick holder is moved?

Section A.3 -- Pulleys

TABLE A.1. Pulley Data ($g = 10m/s^2$)

Data / Pulley set-up	Single	A	B	C	D
# of support strands					
Load Force (N)	10	10	10	10	10
Applied Force (N)					
Dist. Applied Force moves (m)					
Dist. Load Force moves (m)	.2	.2	.2	.2	.2
Work by Applied Force (J)					
Change in PE by Load (J)					
I.M.A.					
A.M.A.					

Pulley Questions

1. For the case of the single pulley, what does the spring scale read when you stop pulling? What does it read when you lower the load? Explain the differences observed.

2. In general, how does the change in potential energy compare to the work done by the applied force? Why?

3. What relation did you see between the number of strands and the mechanical advantage?

4. How did the distance the force acted through change with the mechanical advantage?

5. Summarize how a pulley system works. In particular describe how a pulley redirects and magnifies or reduces the force.

Part II Work

1. Summarize, through sketches and words, how the energy required to generate electricity arrives at the generator from your muscles.

2. Calculate the power required for 1 lamp. For 2 lamps.

3. Hold your hand in front of the lamp. What do you feel? Where does this come from?

4. What happened when you switched from 1 lamp to 2 lamps? Why?

5. Given that 746 Watts equals 1 horsepower, how many horsepower did you generate for 1 lamp? 2 lamps?

6. Explain the difference between the daily use of the word 'work' and the way it is used in 'physics'.

Lab 3 Work and Energy

Apparatus List

Per Lab

Lever Demo

Metal bar, saw horse, chain, blue motor (weighs 1324N [300 lb.])
Back lever display
Bicep lever display
Tricep lever display
Open face watch
Nutcracker & walnuts
Eggbeater or drill (hand turning type)
Door handle with detachable knob
Screwdriver and can with lid
Broom

Inclined Plane Demo

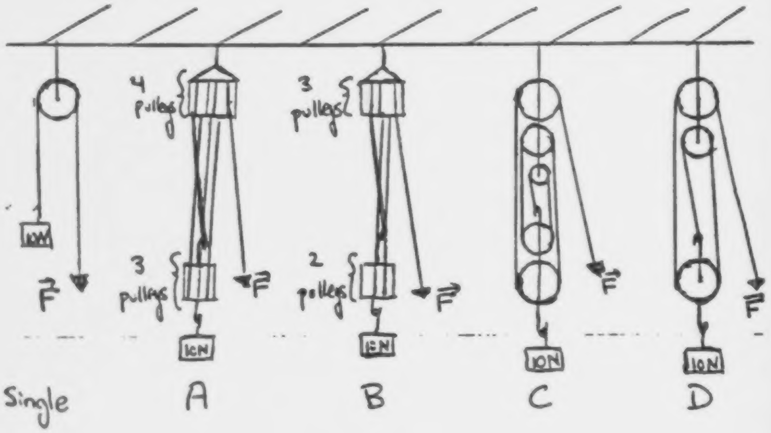
Plank (mount to table 2.5´ from its end
Large protractor
plumb bob
weighted suitcase
15kg spring scale
Screw demonstration from lecture prep.
Lipstick container

Pulley Demo

12 eyebolts overhead
Pulley set-ups shown in figure A.3.1
String
Step ladder
8 1000g weights
8 2000g spring scale
3 single pulleys

Bike Demo

Bike generator



Pulley Set-ups
Fig. A.3.1

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 4 Gas Laws and Heat

Purpose

The goal of this lab is for you to determine the relationships of the gas law ($P V = n R T$), and explain phenomenon of heating and cooling.

Part I Behavior of Gases[1]

The volume of a gas will change if you change either its temperature or its pressure. Apparatus similar to that shown in Fig. 1 will be used to experimentally determine the relationships among these variables.

Section A

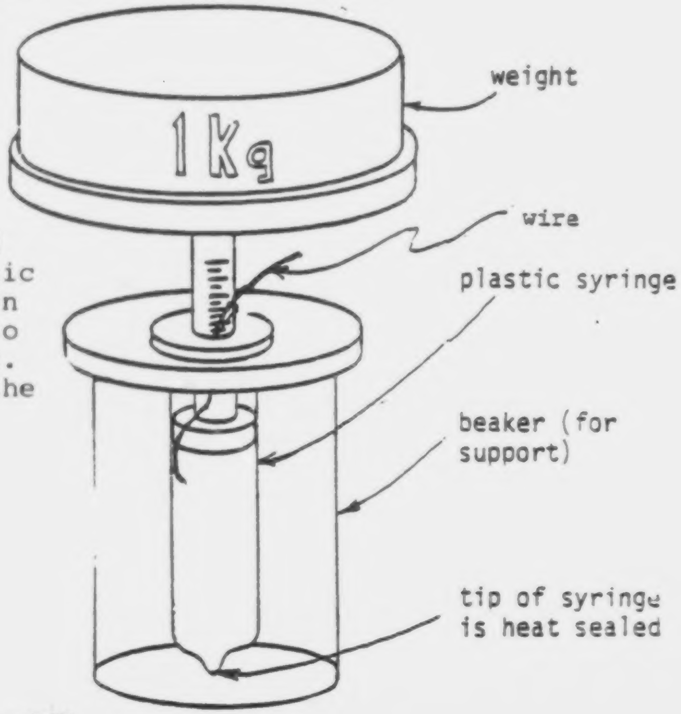
Relationship between volume (V) and pressure (P), holding the temperature constant.

1. Find the diameter of the syringe. Record this on the worksheet.

2. Set the piston near the top of the syringe. This adjustment is best made by placing a string or soft wire along the piston seal when inserting the piston into the cylinder. This will allow some of the air to escape. Withdraw the wire when the piston is at the desired location. In order to prevent scratching of the walls of the syringe, make sure the wire is not kinked. Be sure the air and cylinder are dry because water vapor will effect the results.

Figure I.A.1

Setup for investigating the relationship between volume, pressure and temperature of a confined volume of gas. The plastic tip at the bottom has been cut off and heat-sealed to make the syringe airtight. The wire is used to set the initial volume.



3. Starting with 5N, load the piston slowly with weights up to several 10´s of Newtons, recording the volume, V, for each load. Obtaining the correct volume takes care. After loading the piston you may get better data if you compress the gas a bit more by pushing down on the piston and then releasing. To check that the position of the piston is uninfluenced by friction, twist the piston without pushing or pulling. Record the weight and volume on the table in the worksheet.

   You may want to approach the equilibrium position from above and then again from below and average the results.

4. Determine the pressure, P (in N/m^2) and also the volume V (in m^3) for each of the loads. Your lab instructor will esplain how to calculate these values.

5. Graph your pressure valves, P, in N/m^2 on the y axis against the corresponding valve of Volume, V, on the x axis in m^3.

6. Regraph the data using 1/V on the x-axis. You should obtain a linear relationship.

7. Complete questions 1-4 of the worksheet.

8. Repeat the experiments with one or two other gases. Carbon dioxide (in the form of dry ice) and natural gas are available. Put your work in the tables.

9. Complete questions 5 and 6 of the worksheet.

Section B

Relationship between the volume of a gas and its temperature (holding the pressure constant).

The procedure will be to measure the volume of a gas at the freezing temperature of water and again at the boiling temperature of water, while holding the pressure constant during all the measurements. Instead of measuring the volume of the gas at more than two fixed temperatures in order to show the linearity of the relationship between volume and temperature, we will assume the linearity. We can then construct a graph of volume vs. temperature with only two points. This graph can be regarded as a calibration graph for using the volume of gas as a thermometer. This is, in fact, the approximate procedure followed by early experimenters.

1. Adjust the volume of air so that, while supporting a load of about 20N on the piston, the volume of gas is a little more than half the measured capacity of the cylinder. Immerse the cylinder and piston in a mixture of ice and water using as much ice as possible. Allow some time for the immersed

cylinder and the air to come to the temperature of the ice water bath. Record the volume of the confined air. Measure and record the temperature of the ice water. Keep the beaker of ice water; you will use it later.

2. Using the other 600 ml beaker, place the apparatus in hot water and bring the water to a full, rolling boil. Continue to boil until you are sure the temperature of the confined air is the same as that of the boiling water. Record the volume of the air. Measure and record the temperature of the boiling water. DO NOT let the thermometer bulb rest on the bottom of the beaker. After all the measurements are taken, keep the hot water; you will use it later with other gases.

Section B.2

3. Answer questions 7 and 8.

4. On graph paper mark off the horizontal scale in units of volume including zero volume and the two measured volumes. Mark off the vertical scale in degrees Celsius from -300+o to +100°. Plot your data carefully.

5. Using your "air thermometer" measure the termperature of tap water. Record your value on the worksheet. Also record the value found by using a thermometer.

6. Repeat the experiment (steps A and B) with two other gases such as CO_2 and natural gas and plot the results on the same graph as in II.C. Extend all three lines so that they cross the vertical axis. Determine the temperatures corresponding to zero volume. Record your results on the worksheet. Staple your graph to the back of the worksheet.

7. Answer questions 9, 10, and 11.

Part II Leidenfrost Effect and related stuff

Section A---- Liquid nitrogen demonstrations

Introduction

In this part of the lab you will look at the effect of liquid nitrogen on various materials. This is a qualitative part in that you will be describing what you observe. Just remember that liquid nitrogen is twice as cold as boiling water is hot, therefore be careful not to splash any of the liquid nitrogen on yourself because it might hurt you. A liquid nitrogen freeze will look and feel like a burn.

Apparatus

Dewar, carnation, racquet ball, 2 balloons, rubber tubing, liquid nitrogen

Procedure

Your lab instructor will demonstrate the effect that liquid nitrogen has on various materials. You will be asked to record your observations and explanations on the worksheet.

Section B---- Quench demonstration

Introduction

In this part of the lab you will look at phenomena due to heating. You will try to formulate an explanation of the experiment that you are about to do. The description and Figure II.B.1 below are to be used for reference in completing your description.

The color of an incandescent body is a measure of its temperature. Glass and steel makers can tell if their furnaces are at the proper temperatures just by looking at them. Figure II.B.1 below gives a rough indication of the color produced by a body at different temperatures.

Color of incandescent light	Temperature of Body	
	°C	°F
Incipient dark red	540	1000
Dark red	650	1200
Bright red	870	1600
Yellowish red	1100	2000
Yellowish white	1260	2300
White	1480	2700

Fig. II.B.1 Color of incandescent bodies of various temperatures

Apparatus

One bunsen burner per lab group, matches, two bunsen burners at the back of the room, two additional hot plates at the back of the room, one brass knob and stand per labgroup, two brass knobs at the back of the room, two 600ml beakers at the back of the room.

Procedure

1. Fill the two beakers about 3/4 full with water, one at room temperature and the other just below the boiling point.
2. Heat the brass knob until it is cherry red. (Estimate the temperature; see Figure 1). Record this on the worksheet.
3. Plunge the hot brass knob into the beaker of room temperature water and hold it immersed until it cools. CAUTION: do not let it touch the glass because it may break the beaker. Record your observations on the worksheet.
4. Reheat the brass knob. Take the boiling water off the hot plate. Plunge the hot brass knob into the hot water. Record your observations on the worksheet.
5. Describe quenching in cool and hot water. Explain the differences in the worksheet. (This is the Leidenfrost effect).

References

1. This laboratory is adapted from A Survey of Laboratory Phyics, Part I, by Paul A. Bender. Star Publishing Company, (Belmont, CA, 1985).

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Optional Handout for Lab 4 -- Energy Transfer

EXPERIMENT ON HEAT BALANCE*

This laboratory consists of three parts. Your performance will be judged by Part III only. (But to be able to do Part III you will need to *read* Part I and *do* Part II.)

Part I: Background Information and Principles

Nothing is more important to our existence than the balance between the heat energy we receive and the heat energy we give off. The earth receives heat from the sun and sends heat back into space. Our environment has a temperature such that on the average the heat received and the heat given off are in balance. On a smaller scale of size, the heat balance of houses (which can be controlled by design) can be such that one house will be 10° hotter in summer than another. Finally, the heat balance of our persons can vary widely, due to differences in clothing, for example.

An interesting aspect of heat balance is the so-called *greenhouse effect*. Although you may not own a greenhouse, you have encountered the effect if you have left your car sitting in the sunshine with the windows closed. In countless cases the greenhouse effect has been the Waterloo of the architect, who has designed large areas of glass in the wrong places for artistic reasons, only to find he has produced an oven!

There are three distinct ways that heat can be transferred from one location to another; convection, conduction and radiation. *Convection* is the transport of heated material to a cooler location. For instance, the air near a fire becomes hotter, expands and rises carrying heat away from the fire. *Conduction* is the process by which heat is carried to the handle of a frying pan when the pan is held over a fire. The atoms of the pan in contact with the flame become hot (i.e. they vibrate faster) and cause neighboring atoms to heat up. Thus the heat is carried through the pan to its handle. *Radiation* refers to the transfer of energy by electromagnetic waves. When these waves are absorbed by a body the energy is converted into heat. The sun's energy is carried through almost empty space to the earth by means of electromagnetic radiation, mostly infrared and light waves. Although infrared is not visible, it can be felt, for instance, as the heat from a hot stove or from a fire.

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*A Survey of Laboratory Physics, Part 1, by Paul A. Bender. Star Publishing Company (Belmont, CA, 1985).

Every object continuously receives energy from the outside, and also continuously loses energy to the outside, by one or all of the processes just mentioned. If the rate of receiving energy from the outside is greater than the rate of giving off energy to the outside, the difference goes into raising the temperature of the object itself. If, on the other hand, there is a net outflow of energy, then the temperature of the object will fall. If conditions remain constant for a while, the object will reach a constant temperature, at which the outflow just equals the inflow. It will then be at equilibrium with its surroundings.

In interpreting your experimental results you will need a fact about the absorption and emission of radiant energy. Briefly stated, it is that a given color surface (say black) which is a good absorber of radiation is also a good emitter of radiation, and vice versa. You will also need to know that the rate of emission of radiant energy by an object increases extremely rapidly as its temperature is raised: In fact, as the fourth power. More quantitative statements can be found in your textbook.

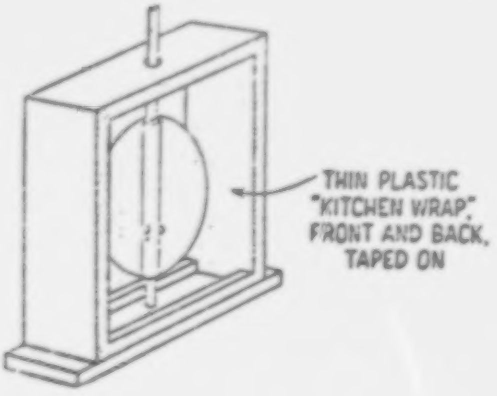
The fact that makes heat balance an interesting puzzle is that an object may receive energy by one means, but may not be able to get rid of it by the same means. For example, if you have a box, painted black on the inside, that has a small glass window, and you project a beam of light into it through the window, radiant energy will go in, but little will come out. The box will have to get rid of the energy by other means, and in order for equilibrium to be reached, the inside of the box may have to get quite hot. This is called trapping of heat; in this case it might be called trapping of radiation. The greenhouse is a form of trap. You will have a chance to observe this effect first hand.

Part II: Introduction to the Apparatus and Basic Measurements

Your source of energy will be light from a reflector flood lamp, which is entirely radiant energy. The beam can be projected onto a copper disc, which has a thermometer in it. When other factors are kept constant (e.g., the distance from the lamp), the initial rate of rise of temperature after the light is turned on will be proportional to the rate at which the energy is absorbed from the light beam. To obtain the rate, you can just measure the rise in temperature in a short interval of time, say one or two minutes.

the plastic stops is negligible (this has been tested) but it does prevent the movement of air. Place the box over the black disk as shown. Heat it up to a little above the starting point you used in the previous exercise on the cooling rate. Shut off the light, and as the temperature falls, get the rate for the same range of a few degrees that you measured when the box was not over the disk (in the previous test).

Figure 2. The "greenhouse"



Part III: Questions and Further Experiments

You have been introduced to some measurements that are possible. Some of the variables are: black or white disk, box or no box, distance from the light, etc. You are on your own to do some further experiments. The list of questions below will suggest experiments, or perhaps require them. A well reasoned and experimentally demonstrated answer will be worth much more than guesses. For each question include reasoning, experimental results, sketches and graphs needed to support your answer.

1. What color clothing would you choose to wear (a) in sunny hot Mexico? (b) for skiing on a very cold, clear day?

A. Measure the initial rate of rise for the black disk. The experimental arrangement is shown below.

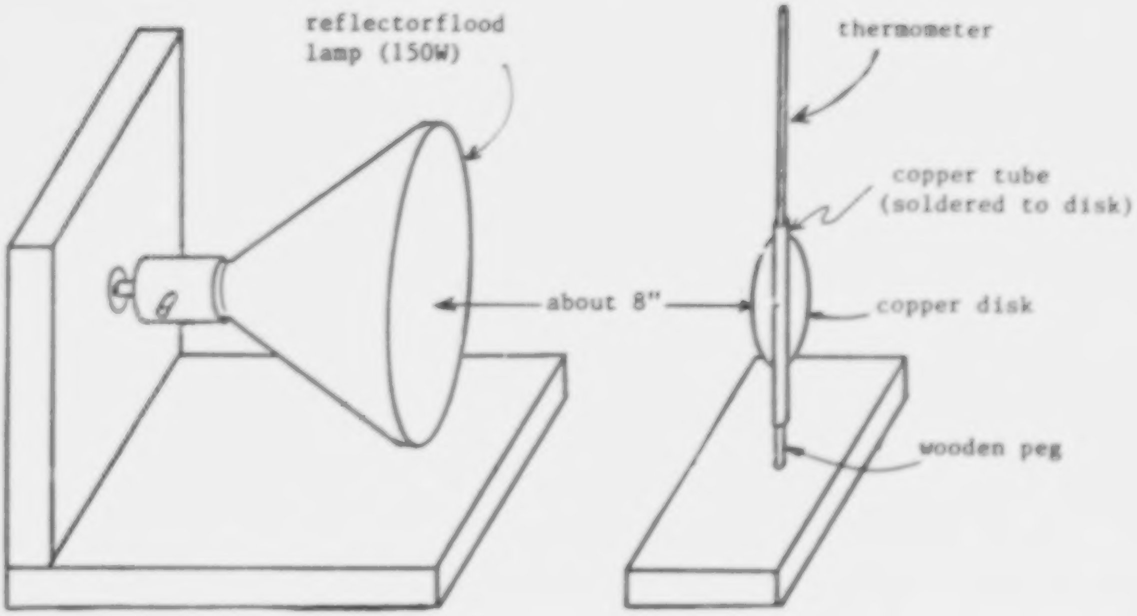


Figure 1. Schematic diagram of the experimental set-up.

After taking the data, plot the temperature against the time (say every 15 sec.) for at least the first two minutes. In this way you can easily determine the rate of increase from the slope of the line using the nearly straight portion of it. Express the result in degrees per minute. (There will always be a curved part at the very beginning, the first 15 sec. or so. This is due to a time lag between the temperature of the thermometer and the temperature of the disk. Ignore this curved part when drawing the straight line.)

B. Measure the rate of cooling, which is proportional to the rate of loss of energy. To do this, raise the disk to some elevated temperature, say 20° or 30° C above room temperature, by projecting the beam onto it. Shut off the beam, and plot the fall of the temperature for about three minutes. (As before, do not use the brief curved part at the very start.)

C. Finally, make a measurement in which the heat loss by convection is reduced. We have provided a box which will enclose the disk. The sides are of extremely thin plastic of the kind used in the kitchen. The amount of radiation

2. How would the temperature of the air in a closed room by affected if you were to stop the sunshine from coming in by hanging a black curtain just inside the window? A white curtain A black or a white curtain just outside the window

3. Imagine a car sitting in the sun. Using your greenhouse, explain how the equilibrium temperature inside will differ in different circumstances, e.g., windows closed or open, white or black upholstery, etc.

4. Some houses have white roofs and some have black, or nearly black. Is there reason for the choice of roof color?

Optional Questions

1. In the sunshine on a very cold day you have a black coat and a transparent plastic coat. How will you arrange these for maximum warmth?

2. Under what conditions will snow that is blackened on top by soot (city air pollution) melt faster than clean snow? Would soot be a suitable agent to use for snow removal?

3. If you were to blow air onto the disk from an electric fan, what would change, heat absorption or loss?

4. You have measured certain things about a white and a black disk. How do you think a reflecting (mirror-like) surface would compare? Would it be like the black, the white, or neither? You may be able to find some aluminum foil.

5. Our planet as a whole (including the atmosphere) received nearly all of its energy in the form of radiation from the sun. By what process(es) does it lose heat?

6. When the rate of loss of heat becomes equal to the rate of gain, the system is in equilibrium, i.e. at constant temperature. Of the various conditions (white, black, greenhouse, no greenhouse) can you give a reason as to which should give the highest, and which the lowest, equilibrium temperature?

Lab 4

Needs

Per Station

2ea. Beakers (600 ml)
1ea. Sealed syringe (on mount)
1ea. Plunger (with weight holder)
1ea. weight set (lg. flat [1] 1/2kg, [2] 1kg,
[1] 2kg....NOTE: Label masses as 1/2kg as 5N
1kg as 10N
2kg as 20N
1ea. Thermometer
1ea. Hot plate
1ea. Bunsen burner
1ea. Brass knob
1ea. Small table clamp
1ea. Brass knob holder
1ea. Wire for syringe/plunger

Optional

1ea. Green house set-up [heat balance lab]
1ea. Black disk
1ea. White disk
1ea. Spot lamp

Per Lab

Dewar
Carnation
Small CO_2 block and cooler
Box of matches
Racquet ball
Rubber tubing
2 balloons
Flask with cork and side extension for tubing
Heavy duty syringe set-up
Spray lubricant

Set-up in back

2 Bunsen burners
2 Hot plates
2 Small table lamps
3 600 ml beakers
2 Brass knobs
2 Brass knob holders

Optional

Box of heat balance stuff...construction paper, filters, foil, scotch tape, plastic wrap
1 Blower

Worksheets for
Laboratory 4 Gas Laws and Heat

Part I

Section A

Title and number your graphs, and staple them to the back of the worksheet.

1. What does the fact that the graph in Section A, step 4 being different than Section A, step 5 indicate about the relationship between P and V?

2. If we write $P = A + B/V$ what value of A and B does your step 5 graph suggest.

3. Using the graph found in Section A, step 5, calculate the value of P for which V is infinite, that is, for which $1/V$ is zero.

4. What is the significance of this value of P? What should its value be?

5. What do you suppose determines the magnitude of the constant B in the relationship between P and V?

6. Does the constant slope depend on the gas?

Section B

Volume of cooled air (in m^3) = ___________

Temperature of ice water = ___________

Volume of warmed air (in m^3) = ___________

Temperature of boiling water = ___________

7. Why should you keep the thermometer off the bottom of the beaker?

8. You might have expected the temperature of the boiling water to be 100°C, but it wasn't. Why not?

What is the temperature of tap water according to your air thermometer? ___________

How does this agree with the value found by a mercury thermometer? How can you account for the difference if there is any?

Volume of cooled carbon dioxide = ___________

Temperature of ice water = ___________

Volume of warmed carbon dioxide = ___________

Temperature of boiling water = ___________

Volume of cooled natural gas = ___________

Temperature of ice water = ___________

Volume of warmed natural gas = ___________

Temperature of boiling water = ___________

Temperature for zero volume of air = ___________

Temperature for zero volume of CO_2 = ___________

Temperature for zero volume of natural gas = ___________

9. How do these three values compare?

10. Is there any meaning to temperatures lower than that corresponding to zero volume? Explain your answer.

11. Write a mathematical relation between V and T. Combine this with the results of part I to write a single equation relating P, V and T of a gas.

Part II

1. Write down what you observed when your lab instructor poured liquid nitrogen onto the table. Why did the nitrogen slide around? Have you ever seen this sort of motion occur when you sprinkle water onto a hot pancake griddle? Explain.

2. Write down what you observed when the inflated balloon was dipped into the liquid nitrogen. Does this agree with the gas law you determined in Part I? Another way to explain what occurred when the balloon is dipped in the liquid nitrogen, is to consider the kinetic energy of the air molecules. From this statement, see if you can explain what you observed.

3. Write down what you observed with the carnation and racquet ball. Explain.

Part III

Estimate of temperature of the brass knob = ____________

1. Observations of the knob plunged into room temperature water:

2. Observations of the knob plunged into hot water:

3. Explain the differences between the two cases. Why does this occur?

Worksheets for
Laboratory 4 Gas Law and Heat

Name ______________________________ Date ____________

Partner's Name ______________________

Part I

Section A

Diameter of the syringe (in meters) = __________

Area of syringe opening (in m^2) [Area = (radius)^2] __________

Table I.1

Gas ______________

Load Weight	Syringe Scale Reading	Pressure	Volume
1.			
2.			
3.			
4.			
5.			
6.			

Calculation Space

Table I.2

Gas ________________

Load Weight	Syringe Scale Reading	Pressure	Volume
1.			
2.			
3.			
4.			
5.			
6.			

Calculation Space

Table I.3

Gas ________________

Load Weight	Syringe Scale Reading	Pressure	Volume
1.			
2.			
3.			
4.			
5.			
6.			

Calculation Space

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 5 Electrical Circuits

Purpose

The goal of this lab is for you to develop understanding of basic circuits used in everyday life.

Series and Parallel Circuits[1]

Introduction

While Thomas Edison was trying to invent the incandescent electric light in 1879, he was also working on a system that would enable this light to be used in the home. That system included central power generators, switches, insulating materials, meters, and many more items.

An important part of this system was a parallel wiring circuit for homes. Up to that time, the only electric lights in existence were the extremely brilliant carbon arc lamps that were beginning to be used for street lighting. These had to be connected in series. The following experiment shows the difference between the two types of circuits.

Apparatus

3-volt source, three flashlight bulbs and sockets, leads

Procedure

Start by setting up the simple light bulb circuit shown below.

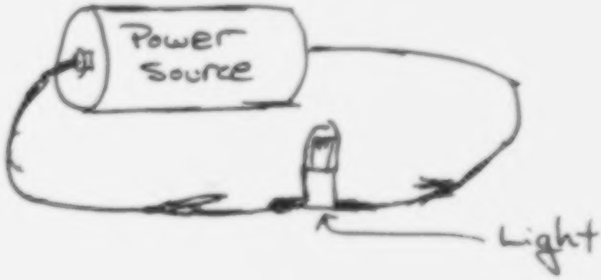


Figure 1 -- Beginning set-up

Start by setting up a series circuit, as shown. When final connections have been made and the bulbs are lit, loosen either bulb. Now set up the circuit for three bulbs in series. Record your observations and answer the questions in the worksheet. Substitute batteries for the battery eliminator and verify that the same results hold.

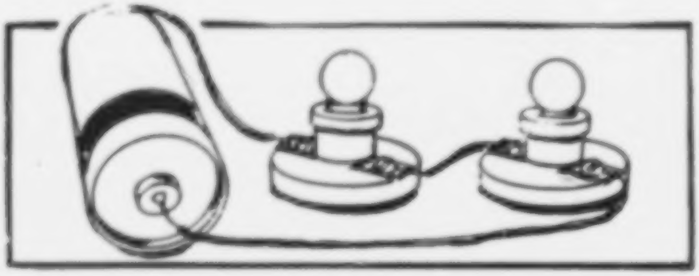


Figure 2 -- Series circuit

Now change to a two bulb parallel circuit as shown in Figure 3. Loosen either bulb. Now set up the circuit for three bulbs in parallel. Again loosen a bulb. Record your observations and answer the questions on the worksheet.

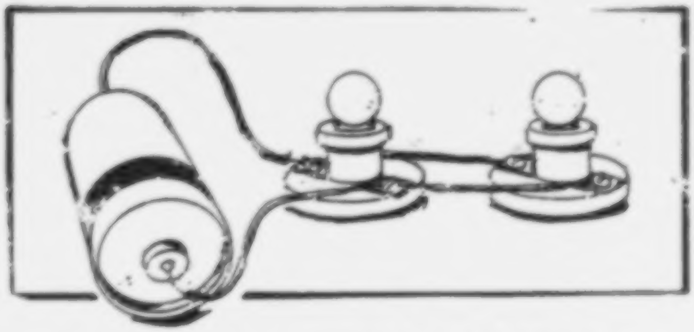


Figure 3 -- Parallel Circuit

Now try a combination circuit, as shown in Figure 4. Record your observations on the worksheet.

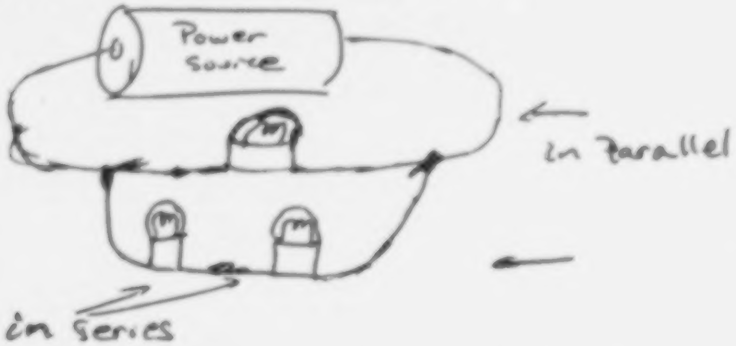


Figure 4 -- A Combination Set Up

Wiring Up[2]

Introduction

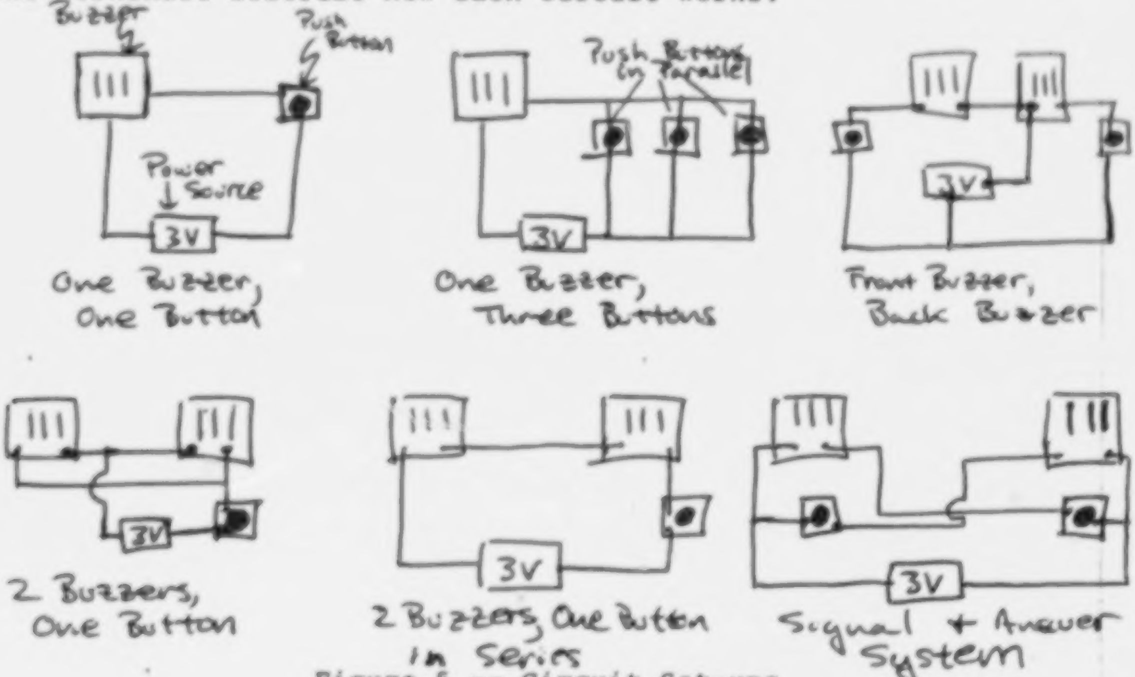
In this part of the lab you will hook-up circuits to see how the various configurations work. On the work sheet you will be asked to explain how the various configurations work.

Apparatus

Two buzzers, three push buttons, 3 volt power source, leads

Procedure

Assemble three of the different circuits shown below. On the worksheet describe how each circuit works.



One Buzzer, One Button

One Buzzer, Three Buttons

Front Buzzer, Back Buzzer

2 Buzzers, One Button

2 Buzzers, One Button in Series

Signal + Answer System

Figure 5 -- Circuit Set-ups

The Special Circuits

Introduction

You will now consider some other circuits. Your lab instructor will demonstrate them to you. During the lab you will have time to go back and develop an understanding of how the circuit works.

Apparatus

House lighting circuit set-up, conducting tester set-up, the fuse set-up, the light bulb set-up, the quiz board.

Procedure

1. House lighting circuit -- study how this one works. Explain on the work sheet the current flow and how the position of the switches explain how it lights.

2. The conductivity tester -- Explain how this circuit works. Complete the table and questions in the worksheet.

3. The fuse -- same as above. Explain how this is important in protecting houses.

4. The quiz board -- Try to determine the circuit before looking at the back of the board.

5. (Optional) The light bulb -- same as above. What did you notice about the influence of air to no air?

References

1. Simple Experiments on Magnetism and Electricity...from Edison, by Robert F. Schultz, Thomas Alva Edison Foundation, Inc., Cambridge Office Plaza, Suite 141, 18280 West Ten Mile Road, Southfield, Michigan 48075 (1979). The material used in this lab was taken verbatim from experiment 10. As a perspective teacher you may want to contact the Thomas Alva Edison Foundation. They have several booklets of excellent science activities (ranging from energy to environmental science). Additionally they have movies and resource units on Thomas Edison and other inventory aimed for the primary and upper elementary grades.

2. Electricity, Boy Scouts of America, Irving, Texas (1985). The diagrams used here were adapted from this merit badge book. As you look for resource material in planning your lessons, consider looking at the Boy Scout merit badge book series. The merit badge book provides an overview of a subject. Also, each book lists several resources that can be utilized by junior high age children.

3. Safe and Simple Electrical Experiments, by Rudolf F. Grad. Dover Publications, Inc. (New York: 1973). Superb collection of electricity and magnetism experiments using everyday materials. A must for every science educator's library.

ATTACHMENT A

Build A Conductivity Tester[3]

Materials

1 1/2 or 6 v Battery
Lamp assembly
Four feet of insulated copper wire
Two pencils with eraser tips
Two thumbtacks

Substances can be divided essentially into two categories. First are the conductors, which allow electricity to flow through them with ease, and second are the nonconductors, or insulators, through which electrons will not travel or at best have a hard time getting through.* Among the insulators are glass, rubber, mica, silk, and oils. The best conductors are metals, but all metals are not equally good conductors. Some are better than others. Silver is the best. Listed below are a few commonly known metals in the order in which they rank as conductors.

1. Silver
2. Copper
3. Gold
4. Aluminum
5. Magnesium
6. Tungsten
7. Iron
8. Tin
9. Lead
10. Mercury

Conductors contain a large number of free electrons and therefore permit electrons to flow easily through them. Though silver is the best conductor, it is too expensive to be used commonly, so copper wire, which is considerably less expensive, is preferred for most electrical work.

When electrons move in a conductor, an electric current is produced. Such a current consists essentially of certain electrons pushing on other electrons that are free to move in the material in which the current flows. Those electrons in turn push others, and so forth down the line. Each electron actually moves only a short distance before it collides with another one; the one that has been hit then moves a short distance, collides with another, and so forth.

Nonconductors, on the other than, have few free electrons and therefore allow practically no current to flow through them. In electrical work they are used as wrappings over current-carrying wires or as support for such wires. When nonconductors are used to keep conductors separated from each other, they are called insulators.

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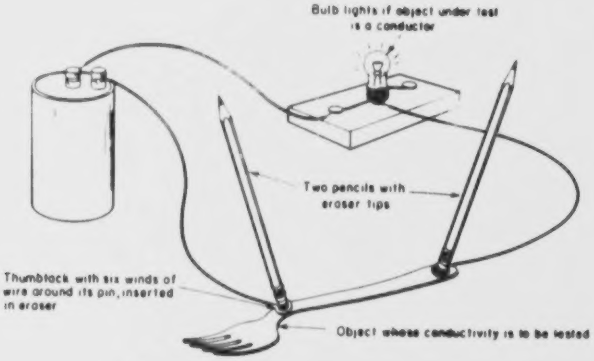
*A new group of materials falling between conductors and insulators, called samiconductors, has been found to be of great importance in the last two decades. These materials made the development of the transistor possible.

Let us construct a conductivity tester which can be used to test materials. Connect one of the terminals of the battery to the bulb assembly. One wire from the other battery terminal and the other wire from the lamp assembly are to be connected to our two test probes.

The test probes are constructed as follows: Clean off all the paint from the heads of two thumbtacks. Also scrape off the insulation for a distance of about 3 inches on the free ends of the wires connected to the battery and the lamp assembly. Wrap the wires (which now have their insulation removed) at least six times around each of the tasks. Then push the tacks firmly into the erasers of the two pencils as illustrated. Your tester is complete. To see if it functions properly, touch the two thumbtack surfaces together. You are completing the circuit, and if all connections are correct, the bulb will light up. Now separate the probes, and let us see how we can use our instrument.

Collect a number of objects which you want to test to see whether they are conductors of electricity or not. Here are some suggestions: A coin, a fork, a piece of cardboard, some nails, paper, cloth, rubber, a key, a piece of wood, a piece of tin foil, chalk, something made of plastic, a metal pot, plus anything else you can think of.


Bulb lights if object under test is a conductor
Two pencils with eraser tips
Thumbtack with six winds of wire around its pin, inserted in eraser
Object whose conductivity is to be tested

Apply your test probes to the objects under test, one at a time, somewhere along their surface. Be sure that you don´t touch the probes´ thumbtacks together while you touch the object under test, but keep them far enough apart so that any current which flows would have to flow through the object under test.

Here is what is going to happen. You will find that with all the metal objects the bulb will light, showing us that they are all conductors. With those objects that are not made of metal, or don´t have any exposed metal surfaces, the bulb will not light up, and we see that they are not conductors of electricity. They are insulators.

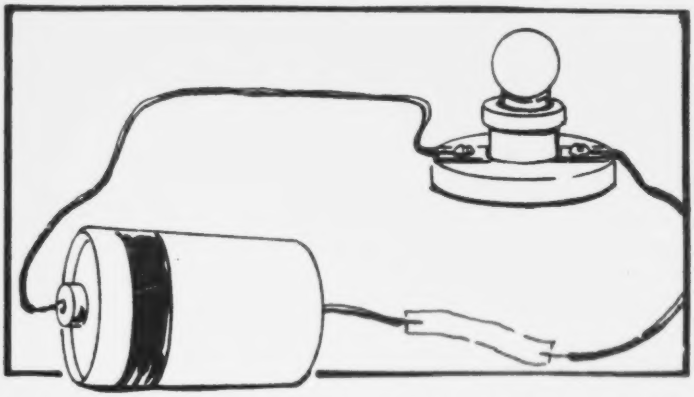
ATTACHMENT B[1]

THINGS YOU NEED. Wire, bulb, socket, and flashlight battery (you may need 2 batteries). A strip of Christmas tree tinsel (silver icicle) or can substitute aluminum foil.

Undoubtedly the smallest, though not the least important, device in Edison´s home lighting system was the fuse. Something like an automatic safety switch, the fuse cuts off the current when it becomes high enough to cause a fire. Dangerously high currents in the main lines are the result of too many branch circuits being used at the same time (overloading the lines). Or they are the result of the "live" wire accidentally touching the "ground" wire or anything else that is grounded, such as a water pipe. This accidental touching is known as a "short circuit."

Edison´s first fuse was patented on March 10, 1880, under the name "Safety Conductor for Electric-Lights." He intended that such a fuse be placed in the circuit of each lamp or other electrical device.

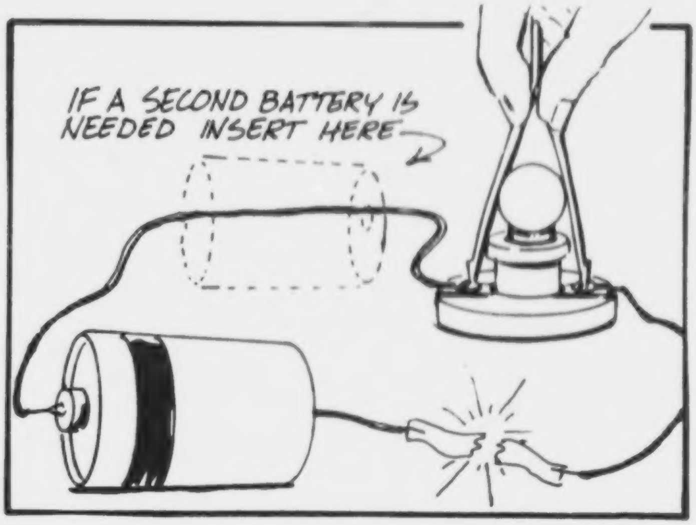
It consisted of a piece of thin, special wire enclosed in a tube made of a non-conducting material. The wire had a low melting point. Whenever a short circuit (high surge of current) developed, the heat of the high current would melt the wire immediately -- opening the circuit before any great damage occurred. The tube served to keep the droplets of molten metal safely contained and to prevent the two ends of the conductor from separating.



You can easily demonstrate how the fuse works. Lay two small lengths of wire on a flat surface so that the wires are in a straight line and 2.5cm or less apart. We´re going to connect a piece of tinsel across the 2.5cm gap. Use tape to make your connections, and be sure there is good contact at both ends of the tinsel. This will be our fuse.

Now comes the test. Connect the fuse wires with the lamp and flashlight battery, as shown. Use tape to hold the wires to the battery ends. If everything is in order, the lamp will light.

To see the fuse in action, we´ll have to produce a short circuit. Do this by touching the two terminals of the lamp socket at the same time with a pair of tweezers or another piece of wire. That will allow the current to bypass the lamp, taking a short cut, you might say.


IF A SECOND BATTERY IS NEEDED INSERT HERE

Without the lamp to act as a resistance, the current becomes much higher than it was. The load will probably be more than the tinsel can carry. If so, the tinsel will overheat, melt, and open the circuit. However, you may have to use two batteries in series, depending on the thickness of the tinsel. If it weren´t for our homemade fuse, the power source would spend itself in seconds.

We get this same kind of protection from our home fuses (and circuit breakers). Edison foresaw the possible dangers of electrical overloads and short circuits. That´s why he felt the fuse was a necessary part of his system.

ATTACHMENT C[1]

Experiment 7 -- Edison´s Electric Light

Materials

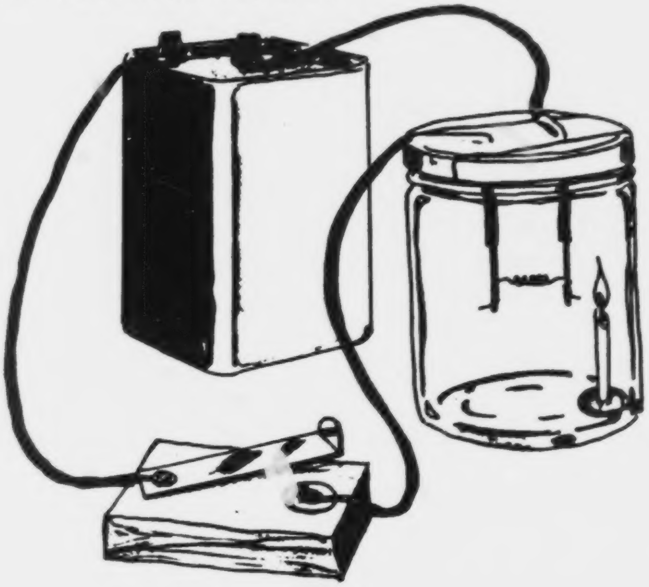
Wide-mouth jar with cover, 1.5m of hookup wire, copper-strand lamp wire 1.5m long, switch, birthday cake candle on a small base, 6-volt battery.

BULB. In the cover, punch two small holes just big enough to receive the wire. Space the holes 4cm apart. Insert two 45cm lengths of wire through the holes so that they will extend halfway into the jar. Now bend the wires down the sides of the cover, and tape them in place. Put a strip of tape over the holes too.

FILAMENT. Remove one copper strand from the lamp wire. Wind it several times around a nail. Slip the coiled filament off the nail, and connect it to the two wires coming from the cover.

LIGHTING UP THE DARK (WELL, NOT QUITE). Screw the cover on the jar. This is our "lamp." Next, connect the lamp in series with the switch and the battery. Turn the lamp on and start counting. The filament will begin to glow. If it continues glowing for more than 15 seconds, open the switch. Otherwise you´ll drain the battery. Try a shorter filament. Keep doing this until you find a length that burns for just a few seconds. When you do, put on a new filament of this length.

Now we´re going to remove some of the air from the lamp. Put the candle inside the jar and ignite it. Then turn out the room lights. While the candle is burning, close the jar tightly. When the candle goes out, which means it has used up a lot of the air, turn the lamp on once again. Hopefully, the filament will glow a little longer this time. Letting it glow in the dark will produce a rather dramatic effect.



ATTACHMENT D[1]

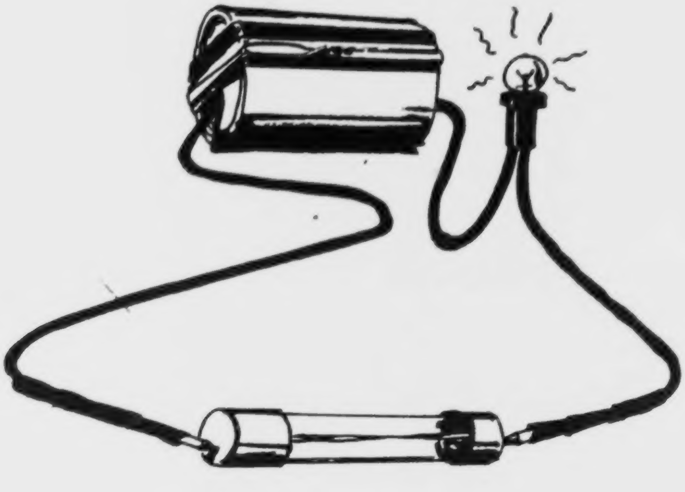
Experiment 8 -- A Light-Bulb Indicator

Materials

2 long thin nails, 2" of hookup wire, bulb socket, screw-type flashlight bulb, flashlight battery, some tape.

We mentioned that the electric light bulb is a simple device. Well in addition, it operates in the simplest of circuits. An example is the light-bulb indicator you are about to put together.

ASSEMBLING THE INDICATOR. Actually there's not much to assemble, as you can see. All you do is hook the light bulb and battery in series and attach the circuit ends to the nails. Make all connections by soldering. But if you have no soldering equipment, use tape. Also cover the nails and nail connections with tape, leaving only the tips exposed.



WHAT DO WE DO WITH IT? Lots of things. For example you can use it in science experiments to learn whether or not different materials and liquids are good conductors of electricity.

You can also use it to check items like flashlight bulbs or glass-tube fuses, as shown. Some of these fuses have wires so thin you can hardly see them. If you touched the indicator nails to the ends of such a fuse and the bulb lit up, you'd know the fuse is OK.

But whatever you do, never use it on anything that is connected to a voltage source (but then you don't need to be told not to stick your finger in a beehive, do you?).

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

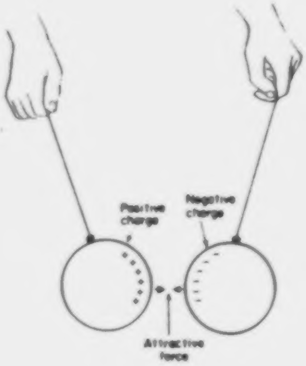
Optional Handout for Lab 5

BRINGING TWO BALLOONS BACK TOGETHER

Materials you will need:

1. Two rubber balloons
2. Some wool or fur
3. Saran wrap
4. Four feet of silk or nylon thread

Blow up two balloons, tie their necks securely, and attach each to a 2-foot piece of silk or nylon thread. Then rub one balloon against the wool, and rub the other balloon with a piece of Saran wrap. Now hold the balloons by their strings, one string in each hand, so that they hang straight down. First hold them quite far apart, then bring them closer together, and note what happens. The balloons will be strongly attracted to each other, and if you let them come close enough, they will eventually touch. As soon as they do touch, they will be neutral again and hang down straight.



Here´s why: That balloon which has an excess of electrons (the one rubbed with the fur or wool) gave up its electrons to the balloon with a shortage of electrons (the one charged with the Saran wrap). As a result of the transfer of electrons when the ballons touched, there was no longer an excess of electrons on the one balloon and no deficiency of electrons on the other. There being no further attraction or repulsion between them, they hang down straight.

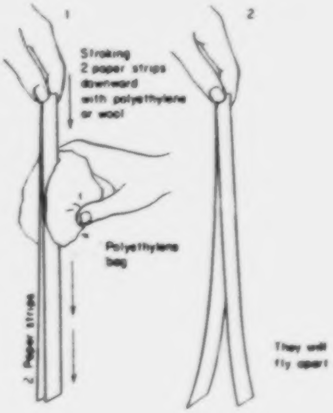
LIKE CHARGES REPEL

Materials you will need:

1. Two strips of newspaper, each about 1 inch wide and 20 inches long
2. Polyethylene bag, nylon stocking, or piece of wool

You can make strips of newspaper fly apart simply by rubbing them. Hold the strips at one end, and let them hang down as shown. You will see that they hang down straight, one next to the other. Now stroke them lengthwise, from top to bottom, with the thumb and forefinger of the free hand. After several strokes they will have acquired a charge. Since both of the strips have the same charge, and we know that like charges repel, they will fly apart.

An even greater charge can be put on these strips, and thus much wider separation obtained, by rubbing them with a piece of polyethylene, such as that used in a cleaner or vegetable bag, or with some wool. Make sure that the outside surfaces of the strips both get rubbed at the same time. Either of these materials will produce a greater charge much faster, so that now the strips will really fly apart, oftentimes after just one stroke.



The charges which were placed on the paper strips as well as on the material we used for charging them will be very readily indicated on the electroscope or charge indicator that we will build in the next experiment.

For further experimentation, try rubbing the strips with other materials, and see which produces the greatest charge. You can also try the same experiment with three or more strips, and you will really see some interesting effects.

To show that charges distribute all over the strips, reverse them. That is, bring the bottoms of the two strips which are now apart together, hold them together, and bring them to the top. Conversely, drop the two ends which were previously held up, and release them. Now you will see that the free ends will again fly apart.

BUILDING AND USING A LEAF ELECTROSCOPE

Materials you will need:

1. Small bottle (milk bottle will also do)
2. Large paper clip or stiff piece of wire (approximately 6 inches long)
3. About 1/2 square foot or aluminum or tin foil
4. Chewing gum wrapper or other source of thin metal foil
5. Rubber or cork stopper to fit the opening of the bottle used

To do this, fold the strip in half (lengthwise) and cut off a little triangle from either side of the fold so as to leave only a very narrow bridge. Then lay the leaves onto the L-shaped section of the wire. The leaves should be straightened out so that they will hang loosely and parallel to each other. Now insert the cork with all its attachments into the bottle, and the electroscope is finished. For best results be sure that everything is dry -- absolutely dry. Otherwise charges will leak off very rapidly, and you may not be able to charge your electroscope at all.

Here is how the electroscope works. If it is touched with a charged object, the charges will run down the wire into the leaves, both of which will get identical charges. Since we know that like charges repel, the leaves will fly apart at the bottom because they are hinged together at the top. Now to use our electroscope.

Rub a comb briskly for about 30 seconds with a piece of nylon (an old nylon sticking will be fine) to give the comb a negative charge. If you bring it close to the knob of the electroscope, the leaves will separate. When the comb is taken away, they will return to their normal position. If you touch the knob with the comb, the electroscope by contact (Figure B). Touching the knob with the finger offers an easy escape path for the negative charge which has been put on the electroscope, and thus the electroscope is discharged.

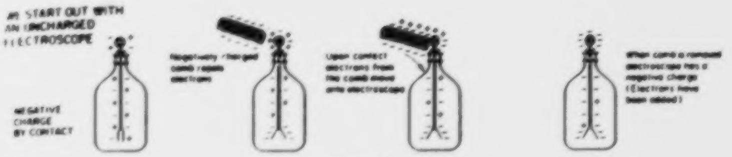

START OUT WITH AN UNCHARGED ELECTROSCOPE
NEGATIVE CHARGE BY CONTACT
Negatively charged comb repels electrons
Upon contact electrons from the comb move onto electroscope
When comb is removed electroscope has a negative charge (Electrons have been added)

Figure B

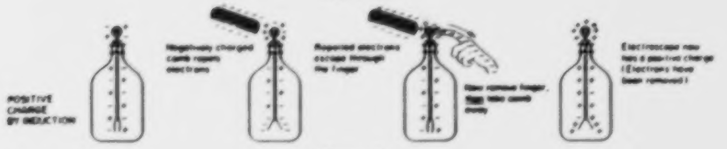

POSITIVE CHARGE BY INDUCTION
Negatively charged comb repels electrons
Repelled electrons escape through the finger
Now remove finger, then take comb away
Electroscope now has a positive charge (Electrons have been removed)

Figure C

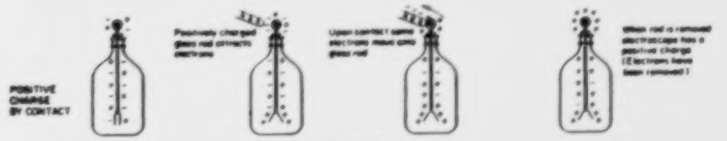

POSITIVE CHARGE BY CONTACT
Positively charged glass rod attracts electrons
Upon contact some electrons move onto glass rod
When rod is removed electroscope has a positive charge (Electrons have been removed)

Figure D

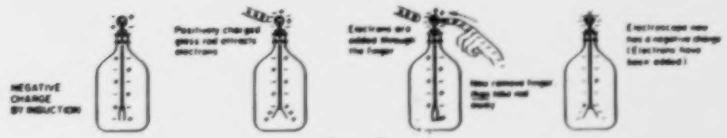

NEGATIVE CHARGE BY INDUCTION
Positively charged glass rod attracts electrons
Electrons are added through the finger
Now remove finger then take rod away
Electroscope now has a negative charge (Electrons have been added)

Figure E

To give our electroscope a positive charge, bring the same charged comb near the knob, and with a finger of the other hand touch the knob for about a second. In doing so, we allow a few additional positive charges to travel from our finger to the knob of the electroscope. Take the hand away from the knob, and then remove the comb. You'll note that as the comb is removed, the two leaves will separate (Figure C). We have now charged the electroscope by induction with a positive charge. Bringing the charged comb near the knob of the electroscope once more will cause the leaves to return to their normal position, and they will separate again as soon as the comb is removed, providing you have not touched the knob of the electroscope.

To give the electroscope a positive charge by contact, touch the knob with a positively charged glass rod as shown in Figure D. To give it a negative charge by induction, proceed as in Figure E.

The electroscope can also be used to determine unknown charges. Here is how: First charge the electroscope with a known charge. Let us assume that we have charged it by contact with a comb rubbed with nylon so that it will now have a negative charge. If we bring the object whose charge is not known near the ball of the charged electroscope, one of two things will happen. The leaves will either separate more or come closer together. If the object is negatively charged, it will repel the electrons on the ball of the electroscope and send them down towards the leaves, thereby causing them to separate even more. On the other hand, if the object is positively charged, it will attract some of the electrons away from the the leaves towards the ball. This will cause the leaves to come closer together, since they are not charged so strongly any more.

The same action will occur, but with opposite charges, if we give the electroscope a positive charge, as we did above. In this case the leaves will separate more if a positively charged object is brought near the electroscope and will come closer together if we approach the ball with a negatively charged object.

How far the leaves separate gives us a direct indication of the relative amount of charge which is placed on the electroscope. Thus the farther they spread apart, the greater the charge. The charge on the electroscope can be accumulated by charging it several times from the same charged object or from another having a charge of the same polarity (positive or negative). The leaves will thus speed farther apart each time an additional charge is put on the electroscope. Before starting any new experiments, always discharge the electroscope first by touching its metal ball with your finger.

Charge the electroscope by contact and by induction from various other objects to become familiar with this simple but important instrument. Make a note of the different amount of charge that various objects produce.

DISCHARGING YOUR ELECTROSCOPE BY RADIATION OR IONIZATION

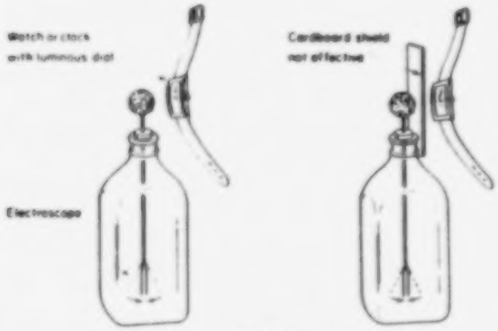
Materials you will need:

1. Leaf electroscope
2. Watch or clock with radiant dial
3. Matches (and candle)

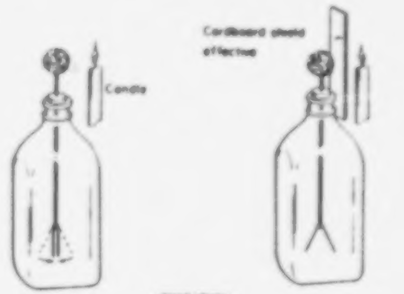
A charged electroscope will become discharged if the air around it can be made conductive. This can be done by placing the electroscope in the vicinity of X-rays or some radioactive material. Hold the radium dial of a clock or a watch several inches from the knob of the charged electroscope and see how quickly it discharges. For best results, the crystal of the timepiece should be removed to permit easier passage of the alpha rays which it otherwise obstructs.

Objects can thus be easily tested for radioactivity by bringing them close to the knob of an electroscope or by actually putting them into the bottle. If the electroscope remains charged for a relatively long time but discharges more rapidly when the object under test is near it, then the object is radioactive. If no effects are noted, then the object is not radioactive.

We can also discharge the electroscope with a lighted candle or match. When a gas (such as air) is heated, the speed of its molecules increases and ionization is more likely to occur, that is, the molecules are more likely to become positively or negatively charged. Bring a lighted candle or a match near the ball of the charged electroscope and you will see that again the leaves will close. The charges have indeed leaked off into the ionized, or charged, air. Now try an interesting experiment.


Watch or clock with luminous dial
Electroscope
Cardboard shield not effective

RADIATION



IONIZATION

Hold a piece of cardboard between the candle and the knob of the electroscope, and you will see that the flame will now have no more effect on the charged electroscope. The cardboard acts as a screen. Try to do the same shielding with the radioactive material. Does it also work? It does not! The cardboard does not act as a shield because those rays or particles emitted by the radioactive material are harder to stop and pass very easily through the cardboard.

HOW TO CHARGE YOUR FRIENDS TO 10,000 VOLTS

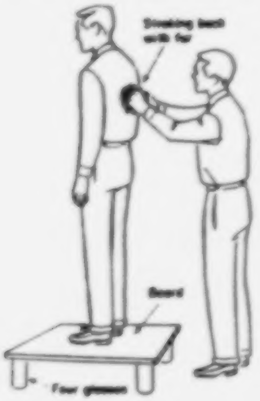
Materials you will need:

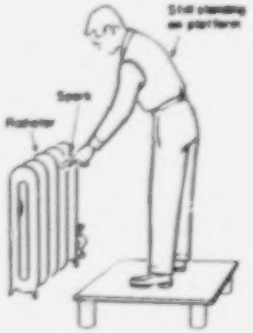
1. Four strong glasses or jars
2. Piece of fur (a fur collar or muff will do)
3. Board or large book
4. A friend

Without the slightest danger, you can charge someone to a potential of thousands of volts and then discharge him by drawing large sparks from his fingers. Let us try it. Before we build our charges, we must be sure we won´t lose them right away, so we have to insulate the person being charged. We accomplish this by means of an insulation platform, for which we need four glasses and a board.

Place the glasses, which must be absolutely dry, on the floor near a radiator or a water tap, and separate them sufficiently so that you can place the board on top and thus construct a stable and safe platform.

Have the person to be charged stand on that platform. Be sure that no part of his body touches anything. Now stroke his back vigorously with a piece of fur for about a minute, and then let him bring his finger near the radiator or the tap. You will see that quite a spark jumps across. The charged person can also touch someone else who is not insulated from the floor and create a nice spark in this way as well.





An electroscope is an easily constructed and very useful instrument for determining the presence of electrostatic charges. It indicates the existence of charges on anything we bring near it, and it will also tell us the polarity of the charges -- that is, whether they are positive or negative. From our previous experiment with the newspaper strips, we know that if we hold two light narrow strips together at one end and give them the same charge,the free ends will fly apart. The electroscope basically consists of the lightest metal foils (or leaves as they are also called) we can find, placed inside some sort of container such as a bottle. The bottle is needed to assure that the sensitive foils are not disturbed by air currents. Construction of the electroscope is very simple and can be accomplished in just a few minutes.

First of all, shape a paper clip or a piece of wire with an L-shaped appendage as shown in Figure A and push it through the stopper that fits the bottle you are using. It is most important that both the stopper and the bottle be completely dry. To be sure that they are, dry them in a warm oven for a little while just before you are ready to assemble the electroscope.

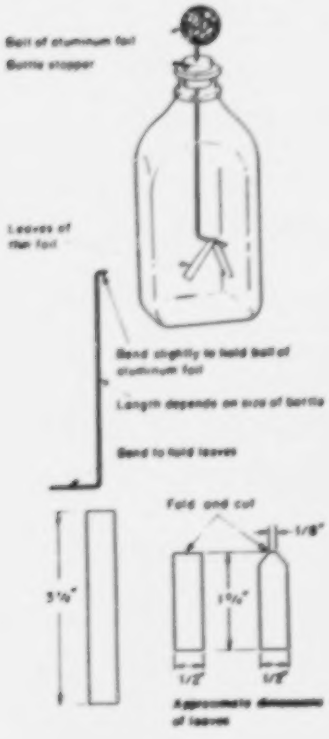


Figure A

About a half inch of the paper clip or wire should be left protruding from the stopper to hold a ball of aluminum foil. This ball should be as round as possible for best results. It is made by packing and squeezing aluminum foil into a little sphere, which is then simply pushed onto the wire.

The leaves are made from the lightest available material. A strip of tissue paper will serve in a pinch, but the foil from a stick of chewing gum is best for our purpose. The paper can be separated from the foil by soaking the wrapper in warm water for a few minutes. The foil and paper will then come apart easily. Straighten the foil, dry it, and cut a strip about 1/2 inch wide and 3 1/2 inches long. In order to make the instrument as sensitive as possible, the leaves should be able to separate with the least resistance, so make them extremely narrow at the point at which they rest on the support.

What you have done is to build up a strong electrostatic charge by rubbing with the fur. This charge may be as high as 10,000 volts or even more. As a further experiment, try rubbing with wool, nylon, rubber, ployethylene, or any other material, and see which gives you the greater charge as indicated by the length of the spark you can draw.

You might also try several layers of ployethylene to stand on for insulation, instead of the glasses and the board.

THE TRIBOELECTRIC OR ELECTROSTATIC SERIES

Now you are on your own. You can experiment to your heart's content in static electricity, and as a guide you can refer to the triboelectric series (also known as the electrostatic series) which is presented here in tabular form.

As far back as 1757, J.C. Wilcke noted that various substances, such as glass, silk, wool, and amber, could be arranged in a triboelectric series. He showed that as you rub any two different materials together, they will become electrified and develop opposite charges. The one higher up on the list will give up electrons and thus become positively charged. The one below will have gained those electrons and thus acquire a negative charge.

Positive Polarity (+)
Asbestos
Rabbit's fur
Glass
Mica
Nylon
Wool
Cat's fur
Silk
Paper
Cotton
Wood
Lucite
Sealing wax
Amber
Polystyrene
Polyethylene
Rubber balloon
Sulphur
Celluloid
Hard rubber
Vinylite
Saran wrap
Negative Polarity (−)

The farther apart the materials are on the list, the easier it is to work with them and the higher the charge will be. You can determine the presence and nature of the chage by means of the charge detector or electroscope. The exact charge on each body depends on its molecular structure as well as the condition of its surface.

From Safe & Simple Electrical Experiments by Rudolf F. Graf

Apparatus List

Lab 5 Electrical Circuits

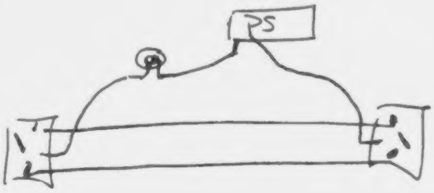
Per Lab Station

1 ea	Battery Eliminator
2 ea	1.5v Battery with holder
3 ea	SPST Momentary switches (on base)
2 ea	1.5v-3v Buzzer on base
3 ea	3v Lamps in socket

Per Lab (center display table)

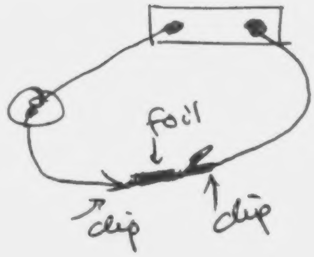
House Switch Circuit
1 Battery Eliminator
1 Board with 2 SPDT switches mounted
1 6v Lamp & socket

Set-up



Fuse Circuit
1 6v Battery
1 6v Lamp and socket
Foil from gum wrappers

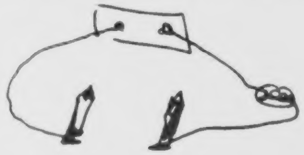
Set-up



Conductivity Tester
1 Box of conductivity material - rubber ball part
wooden ruler
split pencil
plexiglass
foil
popcorn
paper clip
enameled copper wire
scrapped coper wire
piece of metal
chalk

2 leads (thumbtacks & wire pushed into the eraser of a pencil

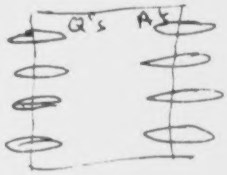
Set-up



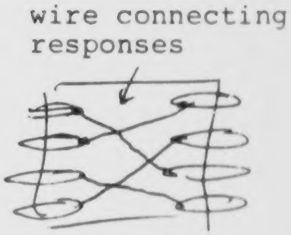
1 6v Battery
1 6v Lamp and socket

Quiz Board

1 Quiz board


Q's
A's
paper clips

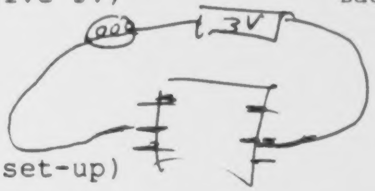
Front


wire connecting responses

Back

2 1.5v Battery in holder
(hooked together to give 3v)
1 3v Lamp and socket

Set-up



Light Bulb (or just use set-up)

1 Jar
1 Jar lid, small holes indented
1 Copper strand lamp wire
1 Birthday candle
Matches
1 6v Battery
1.5m of hook-up wire

Worksheets for
Laboratory 5 Electrical Circuits

Part I Series & Parallel Circuits

Section A. Series Circuits

Record your observations below. Be sure to include sketches of the circuit hookups.

Questions (Reference back to your observations as necessary.)

1. How does the brightness of two bulbs in series compare to that of a single bulb? Three bulbs to two bulbs and a single bulb? What do you think causes this? Explain using the concepts of resistance, current, energy, and voltage.

2. What happened when you unscrewed a bulb? Why? Explain your observations using the concept of current.

3. What would be the difficulty in using this type of circuit in wiring your house?

4. Were there any changes in your observations when you substituted batteries for the battery eliminator?

Section B. Parallel Circuit

Record your observations below. Be sure to include sketches of the circuit hookups.

1. How does the brightness of two bulbs in parallel compare to that of a single bulb? Three bulbs to two bulbs and a single bulb? What do you think causes this? Explain using the concepts of resistance, current, energy and voltage.

2. What happened when you unscrewed a bulb? Why? Explain your observations using the concept of current.

3. What is the advantage of using this type of circuit in wiring your house?

Section C. Combinations

Record your observation. Sketch the circuit.

Explain the relative brightness of the bulbs to each other, using the results of A and C. Be sure to indicate resistance, energy, voltage, and current as they apply in this problem.

Part II   Wiring Up

Circuit Title ______________________

Sketch of Circuit

Explanation of current flow, indicating the action of each button.

Describe how this circuit could be used in a household.

Circuit Title ____________________________

Sketch of Circuit

Explanation of current flow, indicating the action of each button.

Describe how this circuit could be used in a household.

Circuit Title ______________________

Sketch of Circuit

Explanation of current flow, indicating the action of each button.

Describe how this circuit could be used in a household.

Part III The Special Circuits

1. House Lighting Circuit

    a. Sketch the circuit.

    b. Explain how the current flows in relation to switch positions and lighting of the bulb.

2. Conductivity tester (Read Attachment A)

    a. Complete the table. Did the bulb light? (Yes or No) _____

    Material

    Enameled copper wire
    Scrapped copper wire
    Rubber ball
    Wooden ruler
    Plexiglass
    Paper clip
    Chalk
    Piece of metal
    Wooden pencils graphite
    Composite pencils graphite
    Foil
    Pop can (sides)
    Your choice

    b. What type of material can be a conductor?

c. Does the material on the surface of a metal affect its ability to conduct?

d. What type of material acts as an insulator (i.e. non-conductor).

e. What might cause the differences between insulators and conductors?

3. The Fuse -- (Read Attachment B)

   What purpose does a fuse serve?

4. The Quiz Board

   a. Sketch the circuit for the quiz board (without looking at the back of the board).

b. Suggest one use of this apparatus in your classroom.

5. (Optional) The Light Bulb

   a. What difference did you see between the case of a large amount of oxygen to a small amount?

   b. What is the purpose to reduce the amount of oxygen in a light bulb?

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 6 Magnets and Motors

Purpose

The goal of this lab is for you to develop an understanding of how an electrical motor works.

Laboratory Objectives

As a result of this lab, you should be able to:

1. Qualitatively describe through sketches the magnetic field for various configurations of magnets.
2. Describe the effect a magnetic field has on a current carrying wire.
3. Describe the effect of moving a wire through a magnetic field.
4. Describe magnetic shielding.
5. Explain qualitatively how an electric motor works.
6. Build an electric motor.

Part I Magnetic Fields[1]

Introduction

A magnetic field is very different from an electric field. A magnetic field exerts a force on a magnetic "pole" or any magnetized body. Magnetic "poles" come only in pairs, as, for instance, the north and south poles of a compass needle. A compass needle will align itself parallel to the magnetic field at the site of the compass. This is because the north pole of the needle feels a force in the direction parallel to the field and the south pole feels a force in the opposite direction. Iron filings act in a very similar fashion. A long thin sliver of iron becomes magnetized in a magnetic field (magnetic "induction") so that one end of the sliver becomes a north pole and the other becomes a south pole like the compass needle.

Apparatus

1 board with slots for 2 bar magnets, 2 bar magnets,
3 small compasses, paper, iron filings, large iron washer,
baby food jar with corn oil and iron filing mix,
2 disc magnets, bright light, iron filings between two transparencies.

1. Mapping the magnetic field with iron filings: Place a piece of paper over the bar magnet and sprinkle iron filings carefully on the paper. Tap the paper gently until the filings line up in a discernable pattern. On another sheet of paper sketch the pattern. When you are done, pour the filings back into the container. Place a couple of the small compasses around the magnet.

    a. Do they line up along the magnetic field lines?

    b. Is there a direction to the magnetic field around a magnet?

NOTE: Do not pick up the iron filings with bare magnet. The magnet cannot be "turned off" in order to release the filings.

2. The field of two magnets: Using two bar magnets under the paper sketch the field lines indicated by iron filings for the following:

    (1) between two like poles 3/4" apart.

    (2) between two unlike poles 3/4" apart.

    a. Briefly account for the difference between the two patterns.

3. Modification of a magnetic field by the presence of soft iron: Place a piece of soft iron (for example a large washer) between, but not touching, two unlike poles. Again draw the pattern of magnetic field lines. Explain what the washer has done to the field.

    a. Place your explanation here. Be sure to note how the magnetic field has `closed´ down.

b. Move the washer a little bit. What has happened to the field?

c. What is the strength of the magnetic field within the washer hole? Why might this be called magnetic shielding? In particular, what might cause this?

4. 3-D magnetic field: Shake up the jar with oil and iron filings. Place your bar magnets at the sides of the jar. Backlighting the jar will help you see the movement in the iron filings.

   a. Briefly describe the field for a N-S pole, and N-N pole configuration.

   b. Try this with the disc magnets. Note any differences between the fields.

Part II Currents and Magnetic Fields
Hands-on Demonstrations

Introduction

In this part of the lab you will observe the following: the creation of a magnetic field by a current carrying wire; the creation of a current by moving a wire through a magnetic field; the repulsion of a current carrying wire from a magnetic field. The purpose of this part of the lab is to provide you with a logical reason to explain how an electrical motor works.

Apparatus

Compass, galvonometer, close-face horseshoe magnet, wire, 6V lantern battery, metal U {of soft iron} with 2 disc magnets serving as the faces of a small horseshoe magnet, current carrying wire demo

INSTRUCTIONS

Your lab teaching assistant will demonstrate the materials. You will have time later to try the demonstrations yourself.

Section A. Magnetic field created by a current carrying wire

1. Did the wire have any effect before it carried any current?

2. What was the effect on a compass when the current was flowing through the wire? How does this verify that a magnetic field is created? What is the source of net force required to turn the compass needle?

3. Suggest a way to detect electrical wires running through your house.

4. Since a current is defined as $\frac{\text{coulomb}}{\text{sec}}$ what might be the source of the magnetic field?

5. (Optional) Move a compass around on your lab table. See if you can find a current source there. Explain where it comes from.

6. (Optional) Sketch the magnetic field around a wire and a solenoid. Are these fields what you expected?

Section B. Current created by moving a wire through a magnetic field

1. Briefly describe how you determined that a current was created.

2. Was the wire attracted to or repulsed from the magnet before any movement.

3. What might be the cause of the current? HINTS; (a) a magnetic field exerts a force on magnetic poles, (b) a net force results in a movement and (c) a current is moving electric charges which results in the magnetic field.

4. Would you see a difference if the magnet were to move instead of a wire? Why or why not?

5. How are the concepts of this demonstration used in everyday life? (HINT: This is called the "generator effect.")

Section C. Repulsion of a wire by a magnetic field

1. Explain what caused the wire to "jump". HINT: Consider the fact that there must be a net force to cause the wire to overcome its weight. Account for the source of this net force.

2. What do you think determines the magnitude of the jump? List three possibilities. Try an experiment to verify one of your predictions.

3. How do your observations help explain the operation of an electric motor? HINT: Consider the fact that there must be a net force causing the torque which causes the rotor to rotate.

Part III Building a Motor [2,3]

Introduction

An electrical motor is a device that changes electrical energy to mechanical energy by means of magnetism. In this part of the lab you will apply the concepts you have developed to the construction of a simple electrical motor.

Apparatus

Per person:
- approximately .6m of winding wire
- 2 paper clips
- 1 magnet
- 1 wooden block (3" x 2" x 3/4")
- 4 thumb tacks
- 1 - 1.5V battery ("D" cell)
- 2 - 15cm of hookup wire

Per group:
- 1 ruler
- small piece of sandpaper,
- 1 dowel rod form (1/2" dia.)

Per lab:
- 12 pair of pliers
- extra winding wire
- extra batteries
- roll of masking tape
- extra magnets
- scissors
- rubberbands
- 2 pair wire cutters
- 1 wire stripper

INSTRUCTIONS

Making the Coil

1. Cut off .6m of the winding wire.

2. Wind the wire around the dowel to form a coil. Leave about 7cm (3") of wire at each free end.

3. Loop each free end of the wire twice around and through the coil. (See Fig. #1). This is to prevent the coil from unwinding.

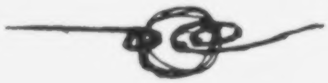


Figure 1 Looping the free ends of the wire coil

4. Remove the insulation from the free ends of the wire. To do this, lay the wire flat on the table. Rub the free ends with sandpaper. Rotate the wire so that you remove the insulation from all sides of the free end.

Making the Coil supports

1. Unbend two paper clips.

2. Grip one of the paper clips at its center with a pair of needle nose pliers. (See Figure #2).

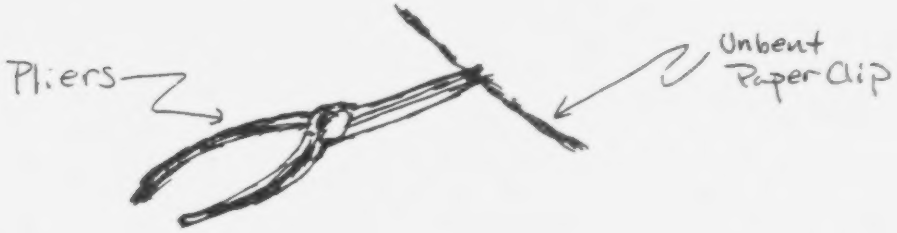
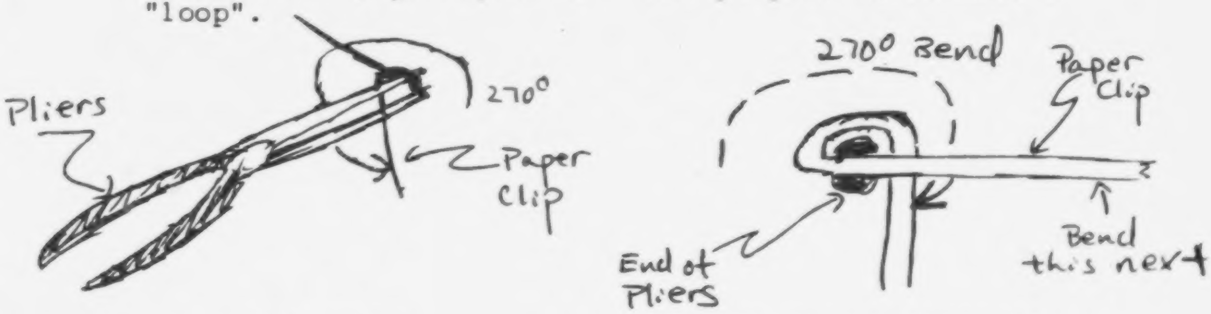

Pliers
Unbent Paper Clip

Figure 2 Gripping the paper clips

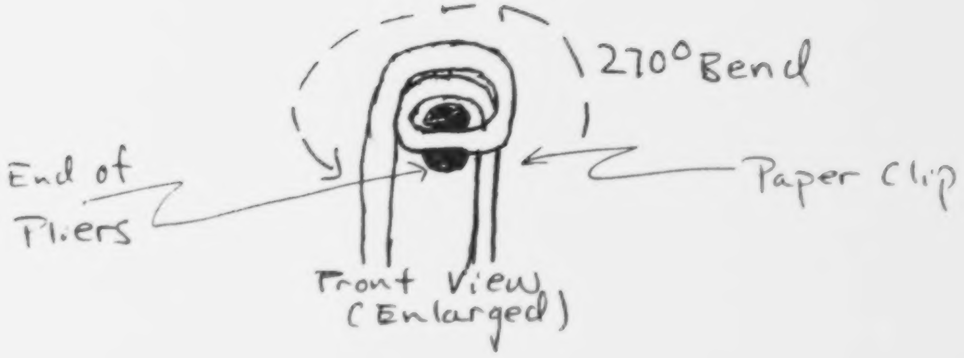
3. Grasp one end of the paper clip. Bend it 270° over the nose of the pliers. (See Figure 3). Repeat for the other end. (See Figure 4). The purpose is to make a "loop".


Pliers
270°
Paper Clip
270° Bend
Paper Clip
Bend this next
End of Pliers

Side View

Front View (enlarged)

Figure 3 Bending the end of the paper clip


270° Bend
End of Pliers
Paper Clip
Front View (Enlarged)

Fr nt View (enlarged)

Figure 4 Completed Paper Clip Loop

4. Bend the ends of the paper clip as shown in Figure 5. NOTE: The distance from the end to the start of the bend is 1.5cm.

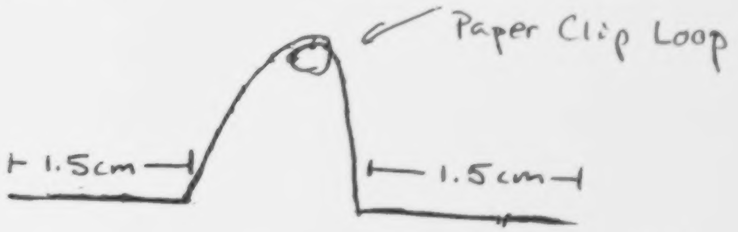

Paper Clip Loop
1.5cm
1.5cm

Figure 5 Bending the ends of the paper clip

5. Bend the ends of the straight part of the paper clip as shown in Figure 6. NOTE: This can be accomplished by gripping the end of the paper clip with the pliers and turning them 180°.

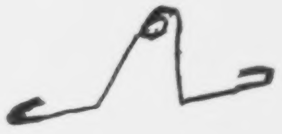


Figure 6 Bending the `U´ into the end of the paper clip to complete the coil support

6. Repeat steps 2-5 for the second paper clip.

Putting the Motor together

1. Cut off 2 15cm lengths of hook-up wire. Strip off 1.5cm of insulation from the wire. These will be the battery hook ups.

2. Wrap one end of each of the battery hook ups around the pin of the thumbtack. (See Figure 7). These will be used in the next step.

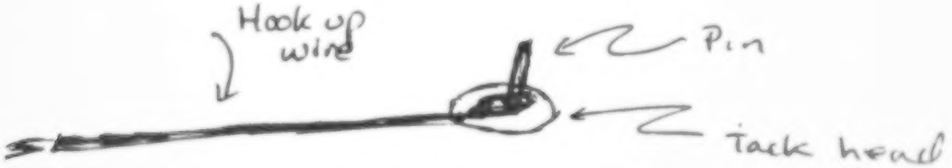
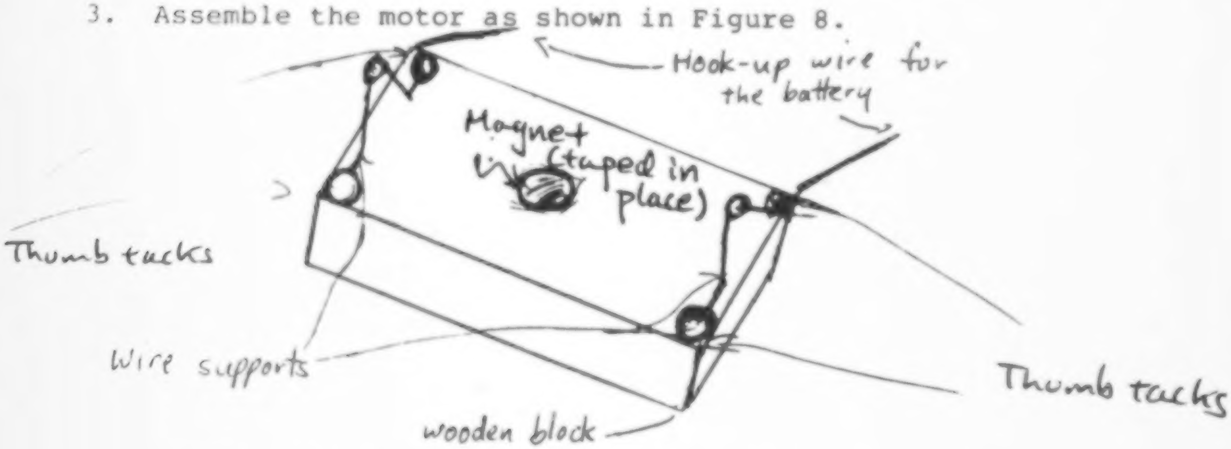

Hook up wire
Pin
Tack head

Figure 7 Wrapping the hook-up wire around the pin of a thumbtack

3. Assemble the motor as shown in Figure 8.


Hook-up wire for the battery
Magnet (taped in place)
Thumb tacks
Wire supports
Thumb tacks
wooden block

NOTE: The thumbtacks are placed in the U-bend. Double fold the tape to hold the magnet in place.

Figure 8 Motor Assembly

4. Place the free ends of the coil in the paper clip loops. You may need to clip a bit off the ends of the coil to fit it easily between the loops.

5. Balance the coil. A balanced coil will spin "evenly" after you twist it. Take your time at this stage.

Powering Up

1. Tape the ends of the battery hook-ups to the terminals of a 1.5V battery. A rubber band wrapped around the battery ends will help insure a good contact. (See Figure 9).

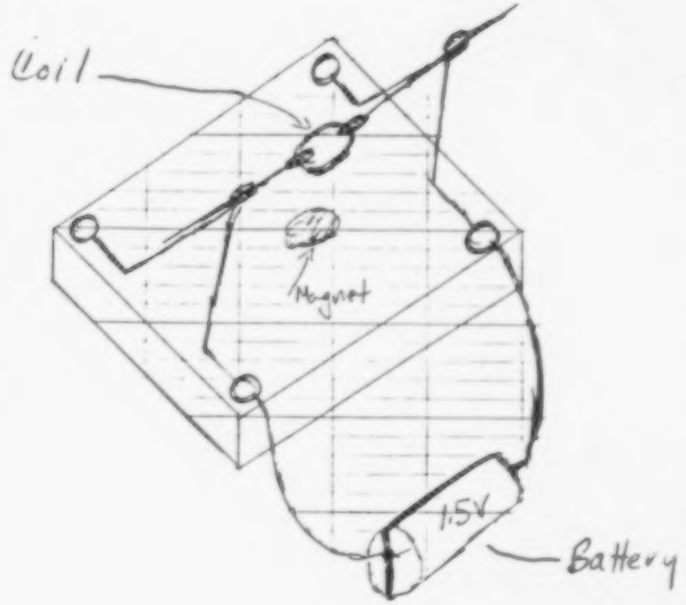


Figure 9 The Completed Motor

2. Spin the coil and it should continue to spin by itself. If it doesn´t spin it again. If the motor won´t work, check the following:
   a. If nothing happens - you may not be getting any electricity.
      (1) Try spinning the coil while the battery hookups are squeezed against the battery.
      (2) Check that the insulation is completely removed from the free ends of the coil.
      (3) Try your coil on someone elses motor setup and battery. If it spins, check your battery and motor setup, then repeat 1 and 2.
   b. If the coil rocks back and forth, but won´t spin;
      (1) check the balance of the coil.
      (2) adjust the free ends so they are wrapped around the center of the coil.

Questions and Discussion

1. In which direction does your coil spin? In particular, what causes the coil to spin? Explain as thoroughly as possible, using the information from the other parts of the lab.

2. Investigate ways to change the direction of the spin. List them here. Give a brief hypothesis of why your method changed the direction of the spin.

3. Touch the metal parts after the motor has been running a while. Do the parts feel warm? Explain in terms of work and energy.

4. In what ways could you increase the speed of the coil. Suggest at least four methods. Try at least one of them (two if time permits). Describe the results.

5. What happens when one magnet is placed on each side of the coil? Does it matter which face you use? (Remember each magnet has a north and south face). Explain.

Optional

6. Use the motor to turn a wind dial or wheel. Describe your success or failure.

7. Find a way to change the motor and make it work better. Describe your result.

8. What might be the cause of the static heard on a radio when it is near a running motor?

Part IV Optional Lab Demonstrations

Introduction

The following demonstrations are an optional part of the lab. They are presented to give you ideas and extend the principles in today´s lab.

Apparatus

Eddy Current Demonstration, Magnetic Attraction Hall Demonstration, magnetic shielding (induction) material (brass, glass, wood, lead, iron, zinc, copper)

WARNING: When working near strong magnetic fields you should remove any magnetic sensitive device from your person, i.e. watches, meal cards, etc.

Section A. Magnetic Attraction Hall Demonstration

1. Move each of the different metal rods through the field of the magnet. What difference was there between each material?

2. Try holding the rods that are most attracted to the magnet in the center between the faces. What difficulty do you have? In particular how does the force of attraction vary with the distance between the rod and a face on the magnet?

3. Determine which is the north and south face of the magnet.

Section B. Eddy Current Demonstration

1. Are the test metals attracted to the magnets?

2. Compare the rate of fall, for the different metals, when dropping normally and then when dropping through the magnet. Record your observations below.

3. Where is the force coming from that cause the net force falling through the magnet to be less than the net force of straight falling?

Section C. Magnetic Materials

1. Test the various materials for magnetism. In general what material is magnetic?

2. What does the magnetic metal do to the magnetic field? That is does it increase it, decrease it, or redirect it?

References

1. A Survey of Laboratory Physics, Part II, by Paul A. Bender, Star Publishing Company, (Palo Alto, CA: 1980).

2. Shoestring Science Experiments.

3. "Activities for Groups," The Physics Teacher, March 1985. This magazine is a good source for activities and explanations. The magazine is designed for high school physics teachers.

Lab 6 Magnets and Motors

Apparatus List

Per Person (Consumable Items) (put in lab box)

1 ea. wooden block (3" x 2" x 3/4")
1 ea. 1.5V (D-cell) battery
2 ea. paper clips (standard size)
4 ea. thumb tacks
1 ea. magnet (ceramic disc)
1 ea. rubber band
1 ea. small piece of sandpaper
2 ea. overhead transparencies frame
2 ea. thick overhead plastic to fit frames

Per Lab

Motor Station (Center table)

Consumable items;
Roll of #22 winding wire (enameled)
(at least .6 meters per person)
#18 hook-up wire (at least 30 cm per person)
1 ea. roll of Scotch mending tape
1/2 lb. iron filings

4 ea. wire strippers
4 ea. wire cutters
6 ea. magnets (ceramic disc)
1 ea. AM radio
6 ea. 1.5V D-Cell
1 ea. scissors
1 ea. box of tacks
1 ea. box of paper clips
2 ea. sheet of sandpaper

Magnetic Field due to current carrying wire demo (center table)

1 ea. 6V battery
1 ea. banana plug wire (long)
1 ea. alligator clip
1 ea. compass
1 ea. 6V 15 amp source (or substitute car battery)
1 ea. momentary contact switch
1 ea. single wire demo
1 ea. solenoid demo
banana plug wire for hook-up

Generator Effect (back of room)

1 ea. homemade horseshoe magnet
1 ea. large horseshoe magnet (close face)
1 ea. galvonometer (100 y A scale)
1 ea. long banana plug wire

Jumping Wire Demo (back of room)

1 ea. homemade horseshoe magnet
1 ea. large horseshoe magnet (close face)
2 ea. long banana plug wire (flexible)
1 ea. alligator clip
1 ea. 6 V battery (or car battery)

Hall Demo

1 ea. magnetic strength

Eddy Current Demo

1 ea. large magnet
copper & aluminum pieces

1 ea. rectanguler bottle with oil & iron filings (put near Eddy Current Demo)

1 ea. box of small magnets (center table)

1 ea. pack of white paper

Per Lab Station

2 ea. long nosed pliers
1 ea. ruler
1 ea. bottle with cooking oil and iron filings
1 ea. board cut to hold magnets
1 ea. bottle of iron filings
2 ea. bar magnets
1 ea. soft iron washer (large)
1 per 2 groups - gooseneck lamp
1 per 2 groups - motor support templates
1 ea 1/2" diameter dowel rod (10 cm long)

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

Laboratory 7 Lenses and Optical Devices

Purpose

The goal of this lab is to introduce you to some of the properties of converging and diverging lenses. You will also learn how to construct a microscope and astronomical telescope.

Laboratory Objectives

As a result of this lab, you should be able to:

1. Determine the focal length of a converging lens and a diverging lens.
2. Construct a simple telescope and explain how it works.
3. Construct a simple microscope and explain how it works.
4. Describe the relationship between the object of a converging lens and its image.
5. Describe the effect of changing the aperature of a lens.

Part I Determing Focal Length

Introduction [1,2]

The focal length of a lens is determined by the curvatures of the two faces and by the index of refraction.

Converging Lens - Any lens that brings parallel light rays to a focus (then, of course, spreads out again) is called a converging or positive lens. The positive refers to the focus being on the opposite side of the lens relative to the incoming light rays. The distance between the center of the lens and the point of focus is called the focal length.

You should note that parallel light rays from an object at infinity will converge to a focus. That is we can find the focal length of a converging lens by focusing on a distant object. The light that travels from a distant object "straightens out" as it travels, just like a water wave started by a drop spreads out from a curved front to a straight front. Therefore, the light from a distant object has effectively parallel light rays.

One further note: A converging lens is one that is thicker in the middle than at its edges, regardless of the curvatures of its two faces.

Diverging Lens[1] - A diverging lens is one that bends a parallel beam so that after the beam leaves the lens the rays spread out, that is, the beam diverges. A diverging lens is thinner at its center than its edge. Although a diverging lens will not bring parallel light to a focus, a focal length is defined for it, as shown in Figure 1.

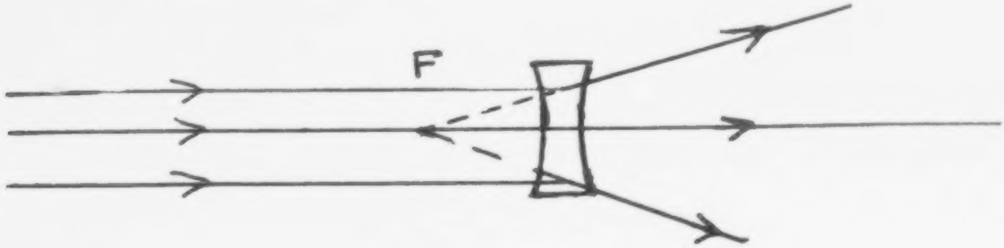


Figure 1. If parallel rays pass through a diverging lens the resultant rays seem to radiate from a point. This is the focal point.

A diverging lens is sometimes called a negative lens. The reason for this is that the focus is on the same side as the incoming light rays.

One further note on lenses: Simple lenses [single lenses] do not have a specified direction. Simply put this means that if we had the incoming light coming from the opposite direction [e.g. the light would come from the right in Figure 1], we would find the focal length to have the same value, even if it changes sides. So, we could say a converging lens has a focus on both sides.

Apparatus

Student telemicroscope equipment, box of lenses (102 lab), white projection cards, ray box and masks, ruler, red lamps, black paper, large clips [card supports].

Procedure

A. Convergent lenses

1. Determine the focal length of the convergent lenses indicated by your lab instructor. Identify each lens for reference. Record your values in centimeters.

2. To complete this measurement face your lens out a window towards a distance object [1 block or more]. For example aim the lens toward the water tower out the east window in the hallway. Use the meterstick as a base.

3. Move the card back from the lens until the image of the distant object is in focus.

4. Measure the distance from the center of the lens to the image. Record your measurements in Table 1. (At the end of B).

5. Reverse the lens and show the focal length is unchanged.

6. Repeat for the other lenses

B. Divergent Lenses[2]

1. Determine the focal length of the indicated divergent lenses, in centimeters.

2. Arrange the apparatus as shown in Figure 2. Make sure the central ray traverses the lens without being bent. This ray then lies along the `optical axis´.

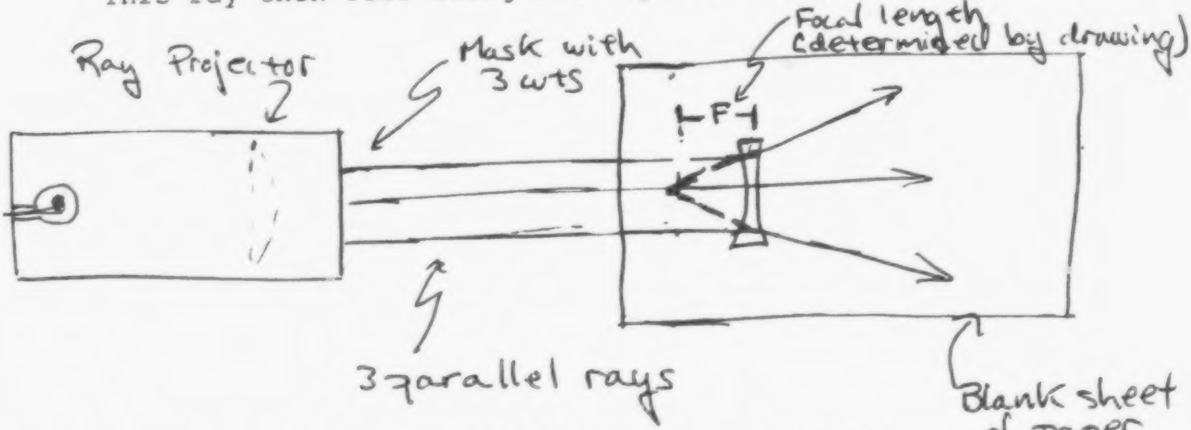


Figure 2. Experimental measurement of the focal length of a diverging lens.

3. Note how the rays diverge after leaving the lens. Mark the direction of the three rays, remove the lens, and extend the rays <u>backwards</u> until they intersect the central ray, [which lies on the optical axis]. The distance between the intersection point (focus) and the center of the lens is the focal length of the lens.

4. Reverse the lens and show that the focal length is unchanged.

5. Record your value on the table [at the end of this section]. Staple your drawing to the report.

6. Repeat for the other divergent lenses.

Optional

A. Use the set up for divergent lenses to find the focal length of a convergent lens [the lens on the aluminum mount]. The only difference in the set up is shown in Figure 3. Note: The center ray is again the optical axis.

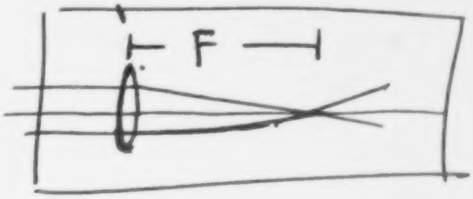


Figure 3. Experimental measurement of the focal length of a converging lens.

1. What difference was there in the value you found by focusing on a distant object? Account for the difference.

2. Borrow someone´s glasses. Devise an experiment to determine if the person is "nearsighted" [his/her glasses would have divergent lenses] or "farsighted" [his/her glasses would have convergent lenses]. Describe your experiment. Was your experiment a success?

NOTE: F = Focal Point; M = Magnification

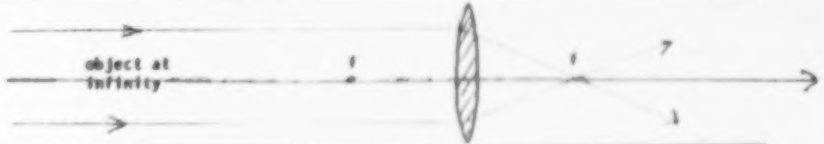
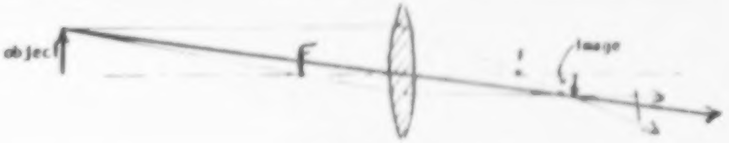
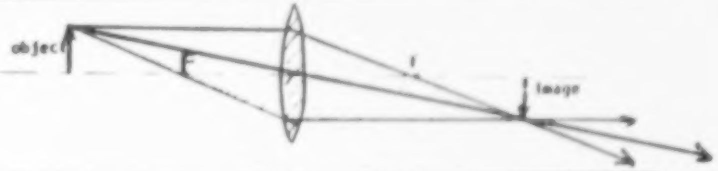
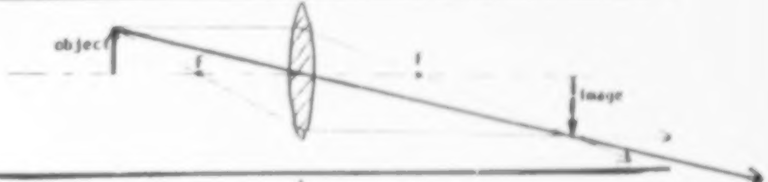
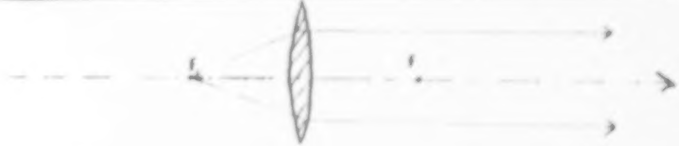
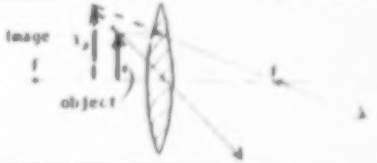
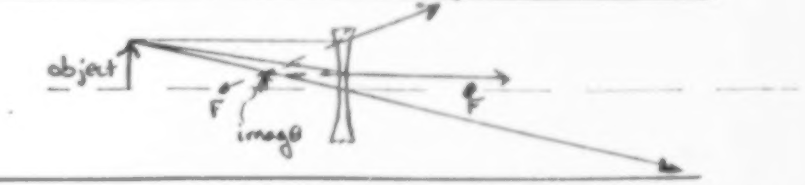
	Location of Object	Location of Image	Character of Image	Typical Uses	Ray Diagrams
	--Converging Lenses--				
I	at infinity	at F		objective lens of astronomical telescope burning glass	
II	outside 2F	between F and 2F	real inverted reduced (M 1)	camera eye objective lens of binoculars	
III	at 2F	at 2F	real inverted same size as object	camera for copying (1:1)	
IV	between 2F and F	outside F	real inverted enlarged (M 1)	slide or movie projector photographic enlarger flood light lens microscope objective lens	
V	at F	at infinity		search light spotlight	
VI	inside F	same side of lens as object	virtual erect enlarged	magnifying glass eyepiece (ocular) of telescope or microscope	
	--Diverging Lens--				
I	Any-where	inside F	virtual erect reduced (M 1)	eye glasses eyepiece of a telescope	

Figure 4. Imaging properties of lenses*

*Adapted from Experiments in Physics, Physics 202 by Paul A. Bender and J. Thomas Dickinson. Star Publishing Company, (Belmont, CA: 1985).

TABLE 1. LENS FOCAL LENGTHS

Identification	Type [Convergent or Divergent]	Focal Length
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

Part II Imaging Properties of a Lens

Introduction[1]

Various aspects of images formed by a converging and diverging lens are shown qualitatively in Figure 4. You will look at the images formed as you change the distance from the object to the lens from a separation of one focal length to a separation of two focal lengths. You will next consider the case when the object is separated from the lens by a distance of less than one focal length.

A. Imaging with the object outside one focal length (F)[1]

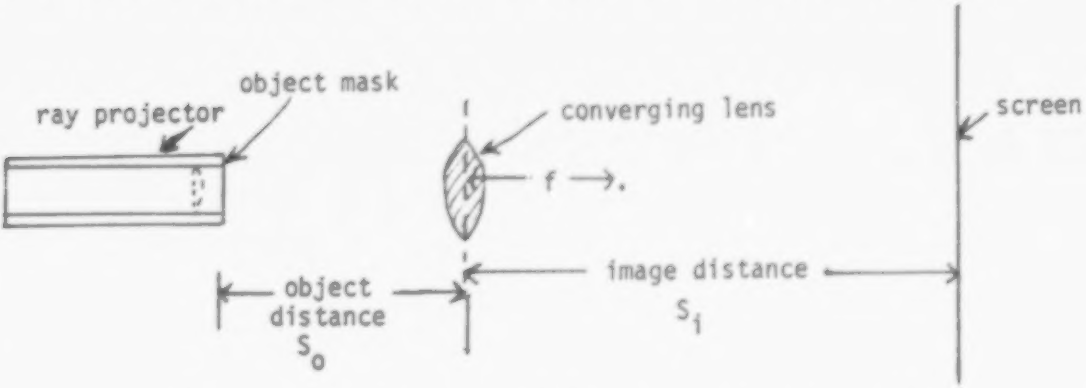

object mask
ray projector
converging lens
screen
f →
object distance S_o
image distance S_i

Figure 5. Setup used for investigation of the relationship between image distance, object distance and focal length.

Procedure

a. With the "object mask" in the ray projector, place the ray projector and the screen a distance apart equal to about five times the focal length of the converging lens. (See Figure 5).

b. Now place the lens on a line between the projector and screen and move it back and forth until you find a sharp image on the screen. Note that there are two positions of the lens for which you get a sharp image. These correspond to configurations II and IV in Figure 4.

c. Do your observations correspond to II and IV in Figure 4? That is, are the images [size and inverted] and location distances as predicted by Figure 4? (You need only take rough measurements to confirm this).

d. Under what conditions is the image larger than the object? .....smaller than the object?

e. What happens as the distance between the lens and object is about one focal length [look on the far wall]? What happens when the distance is less than one focal length [i.e. is an image formed on the screen or far wall]?

B. Imaging with object inside one focal length[1]
- The Converging lens as a Magnifier or Eyepiece

When you try to look at the fine details of an object that is far away, the image formed on your retina is very small. So, you bring the object closer making the image larger and the fine details stand out. However, as the object gets to near the eye, (less than 25 cm) your eye can no longer focus the object. The problem, is to be able to bring the object very close, so as to get a large image on the retina, and still keep the image sharply focused.

The solution is to use a convergent lens with a short focal length. The lens forms a virtual image of the object, when the object is just within the focal length, and the eye looks at the virtual image. Refer to Figure 6.

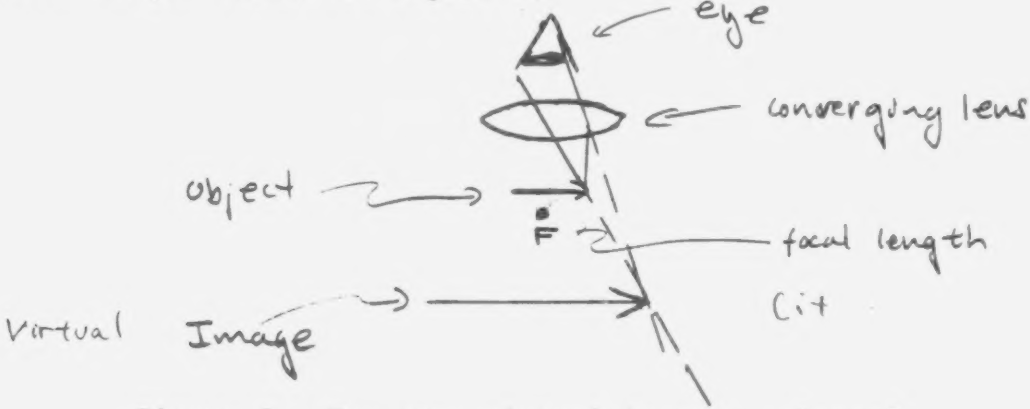


Figure 6. Eye sees virtual image = enlarged and erect.

The Converging Lens as a Magnifier - You showed in answering question e above that if the distance between the object and the lens becomes less than the focal length you could not produce an image on the screen. This is illustrated in Figure 4. When the object is within the focal length the light rays are bent toward the axis of the system, but they still diverge and do not form an image. One can still see an image, however, if you look back through the lens at the object. It is not a "real" image, which can be projected on the screen as you did in the previous section, but is called a "virtual" image: one you can see, but is not projectable.

When you use a converging lens as a magnifier, hold the lens close to your eye, bring the object close to the lens (within the focal length of the lens) and adjust distances until you see a focused image at about 25 cm, the "normal" reading distance. Under these conditions the magnification is given by

$$m_{maximum} = 1 + 25/f \qquad \text{Eq. 1}$$

Instructions

Use the "student´s telemicroscope". The lenses and the transparent grid, which will be used as the object, are mounted in black plastic holders with magnetic mounts. Put the 40 mm focal length lens, the magnifier, at the 0 cm mark on the scale and the grid at about the 4 cm mark. Put the card with the graph on it into the card holder and put the card holder at the 25 cm mark. Note that the card holder mounts on the telemicroscope so that the adjusting knob is on the opposite side from the cm scale.

With your eye close to the lens look through it and focus by moving the grid. The following procedure is to measure the magnification of your magnifier. With one eye close to the lens look at the transparent grid through the lens while looking with the other eye around the lens at the graph paper. The virtual, magnified image of the transparent grid should be formed at the distance of the graph paper. To check this move your eye back and forth across the lens and look for relative motion (parallax) between the image and the graph paper. You can now compare the image size with the graph paper and estimate the magnification. Repeat with the 25 mm focal length lens.

a. Which lens magnified the grid the most?

b. Why did you need to move the grid up when you used the 25 mm lens?

c. Was the image erect?

Part III Optical Instruments [1,2]

Introduction

In this part of the lab you will construct various optical instruments, using the principles developed earlier.

Apparatus

Single filament bulb, lab jack, student telemicroscopes kit, white projection cards

A. Astronomical (Keplerian) Telescope

Introduction

Figure 7 shows the paths of light rays in a simple astronomical telescope.

The magnification of a telescope is not defined as the ratio of the sizes of the image to object. It is defined as the ratio of the angles subtended by the image and the object as shown in Figure 8.

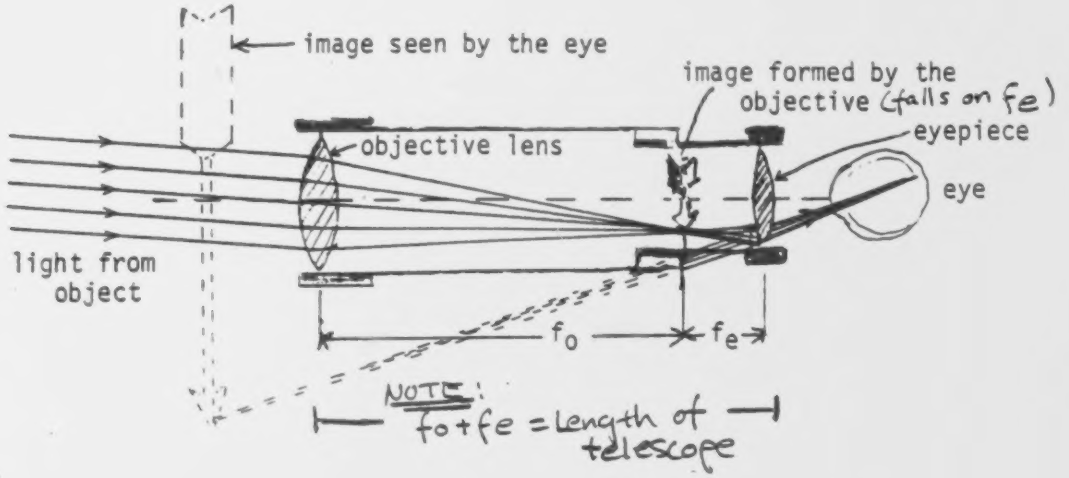


image seen by the eye
image formed by the objective (falls on fe)
eyepiece
objective lens
eye
light from object
f_o
f_e
NOTE: fo+fe = Length of telescope

Figure 7. Illustration of the paths of light rays in a simple astronomical telescope

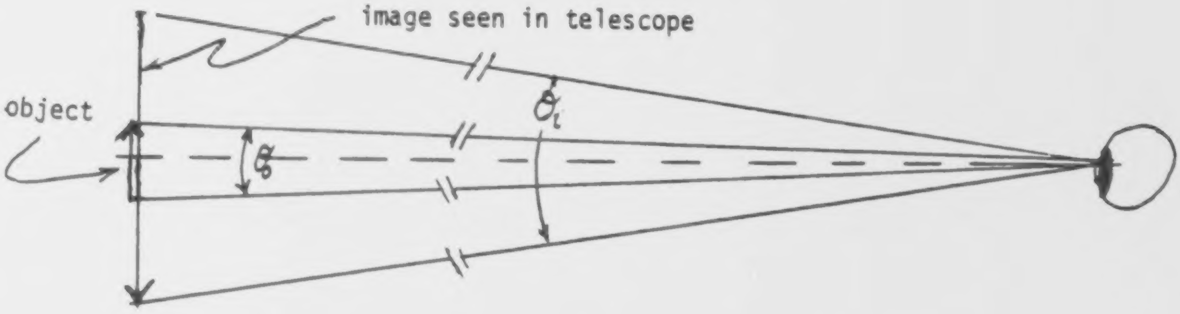


image seen in telescope
object
θ_i
θ_o

Figure 8. The magnification of a telescope is defined as θ_i/θ_0. Both images are at infinity. (Refer to Figure 4.)

It can be shown that if the object is far away from the telescope (i.e. greater than 20 times the length of the telescope) the magnification of the telescope is given by;

$$M = \frac{\text{focal length of objective}}{\text{focal length of eyepiece}} \quad \text{(magnification of a telescope)} \qquad \text{Eq. 2}$$

From Equation 2 you can see that to increase the power of a telescope you must increase the focal length of the objective (and therefore the distance between the lenses) or decrease the focal length of the eyepiece. These conditions have led to astronomical telescopes of enormous lengths, up to several hundred feet between the lenses. However, the problems of keeping the lenses rigidly aligned in the wind and still being able to point the telescope to different portions of the sky have kept most telescopes under about 40 feet in length.

With astronomical telescopes it is more important to have a bright image than to have high magnification. The amount of light entering the eye or the photographic plate is determined by the area of the objective lens. By increasing the area of the objective, the amount of light forming the final image is increased, thus enabling more distant stars to be seen. Because of this, astronomical telescopes are usually classified by the diameter of the objective rather than by their focal length or power. A telescope is designed to bring a distant object closer.

Instructions

An astronomical telescope consists of an objective lens (so called because it is facing the object) of long focal length, f_o, and an eyepiece of short focal length, f_E. Construct a telescope using the telemicroscope as follows: Put the 105 mm lens (the objective) at the 13 cm mark and focus the image of the bare bulb, which is across the room, onto a white card which is in the card holder at about the 4 cm mark. Now put the small aperture 40 mm lens (the eyepiece) near the o cm mark and focus on the back of the card. Now, while pointing at a distant object (not the bulb, it may be too bright) pull the card out. You should now have a focused telescope! Repeat with the 40 mm lens as the eyepiece. This procedure should emphasize that the eyepiece acts as a magnifier "looking" at the image of the objective.

Questions

1. Is the image inverted or erect?

2. Describe in your own words how a telescope works. That is start with a distant object and explain how the image makes its way to the return of your eyes. Use sketches as necessary. Be concise. (Hint: Identify the object and image of each lens separately and relative distances.)

3. What is the distance between the lenses, in terms of the focal lengths of the two lenses? Find this distance. Does this distance change if the object distance changes?

Optional

Galilean Telescope - The Galilean telescope, or opera glass, consists of a converging lens of long focal length as the objective, as in the astronomical telescope, but the eyepiece is a diverging lens. Put the diverging lens at the 0 cm mark of the telemicroscope close to your eye and using the 105 mm lens as the objective find the correct distance between the lenses to focus on a distant object.

Questions

1. Is the object erect or inverted?

2. What is the distance between the lenses in terms of the focal lengths. Do not forget that the focal length of a diverging lens is negative.

B. Compound Microscope

Introduction

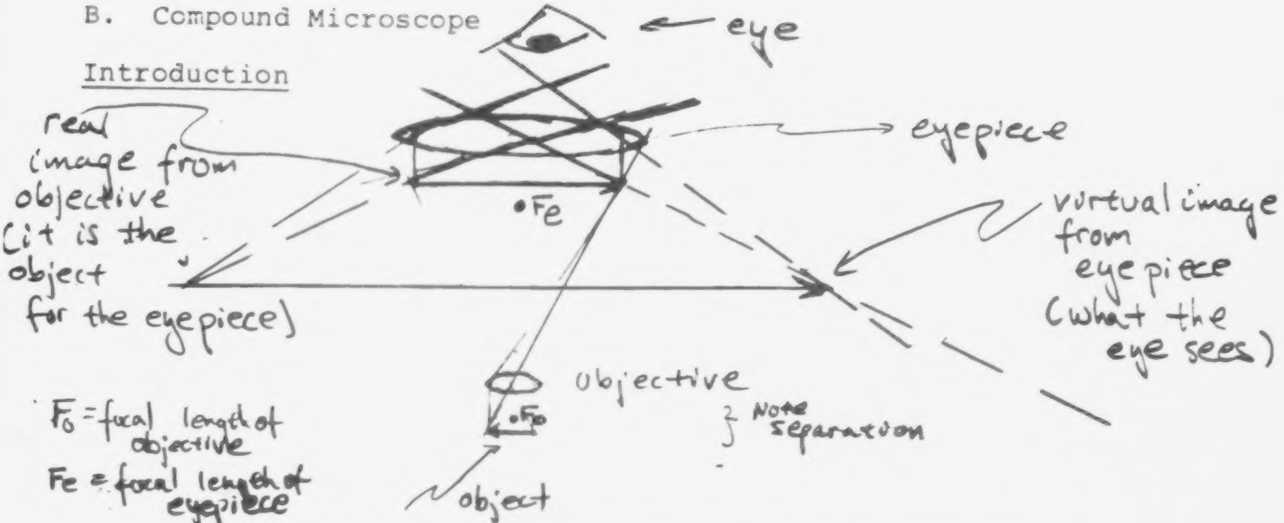

eye
eyepiece
real image from objective (it is the object for the eyepiece)
•Fe
virtual image from eyepiece (what the eye sees)
objective
•Fo
Note separation
object
Fo = focal length of objective
Fe = focal length of eyepiece

Figure 9. Diagram of the compound microscope

The action of a compound microscope is illustrated in Figure 9. The magnifying power of a microscope is defined in the same way as for a telescope.

$$\text{magnifying power of instrument} = \frac{\text{visual angle of image seen with instrument}}{\text{visual angle seen directly}}$$

More useful is the formula, derived from the definition above, that,

magnifying power of a microscope = magnifying power of the objective times the magnifying power of the eyepiece.

The magnifying power of the objective is the ratio of the size of the image formed by the objective (first image) to the size of the object. This, of course, is not a fixed number for any given lens. However, in a commercially built microscope the image distance is fixed by the length of the optical tube (an optical length of 160 mm is now almost universally adopted). Thus, since the image distance is fixed, the object distance is also fixed and the magnifying power for the lens is determined. The magnification is clearly marked on the lens mount of most objectives.

Since the eyepiece is being used as a magnifying glass to view the image formed by the objective, the magnifying power of the eyepiece is determined by the same formula as for the magnifying glass, which is

$$\text{magnifying power of the eyepiece} = \frac{25}{f_e} = 1$$

(f_e is the focal length of the eyepiece measured in cm.) The power of the eyepiece is usually marked on its mount.

Instructions

A compound microscope (as opposed to a simple microscope, which is a magnifying glass) is a device which at its simplest consists of two lenses, an objective and an eyepiece. The object is placed just beyond the objective's focal point and produces a real, enlarged image of the object. This image is viewed, with additional magnification, through the eyepiece. Set up the microscope using the telemicroscope. As the eyepiece put the small aperture 40 mm lens at the 0 cm mark. Put the large aperture 40 mm lens, as the objective, at the 20 cm mark. Put the card containing graph paper in the card holder at the 25 cm mark. Adjust the microscope until the graph is in sharp focus. Carefully note the positions of all the components. Estimate the magnification by superposing the image as seen through the microscope with the object seen directly as you did with the magnifying glass.

Questions

1. How much did your microscope magnify?

2. What is the distance between lenses in terms of the focal lengths of the two lenses?

3. Describe in your own words how a microscope works. That is start with the object and explain how the image makes it to the retina of your eye. Use sketches as necessary. Be concise. (Hint: Identify the object and image of each lens separately and distances.)

4. What lens combination might increase the magnification? Try it and report your results here.

Part IV Optional Demonstrations

Apparatus

Find your height mirror, polarizing display, optics display box, aperature reducing material, large lens hall demo

A. Find your height mirror - The instructions are on the mirror.

1. Sketch a ray diagram explaining what is occurring.

B. Large lens hall demo

   1. What type of lens must this be? Why?

C. Aperature experiments - (A write-up explaining use with cameras is found near the lens). The aperature (opening of a lens) determines the amount of light that will reach the "screen". Cameras use this to control the amount of light energy that will reach the film. Your eyes have an iris that will change your pupil diameter to regulate the amount of light.

   The aperature does not change the focal length. It also does not lose any of the image.

   1. Play with the aperature opening on the camera lens located in the optics display box. Describe how the aperature is changed.

2. Tape a small circle of tape to one of the convergent lenses with the aluminum bases. Go into the hallway to refind the focal length. Was there any change in F? How did the intensity change? Did you lose any of the image? Block off half the lens and see what happens. Report your observation here.

3. Use the ray box and a convergent lens. Project an image of the object mask. Block off various parts of lens. Record your observations on intensity and loss of image.

4. Summarize the effect of changing aperature.

5. Why, based on your observations, do telescopes want a large objective?

D. Polarizing Materials - This is a "fun" hands on display. A write-up explaining what is occurring is located near the box.

E. Optics Box Demo - Experiment with the various items. Notice that just because a lens is cut in half does not mean it won´t work.

References

1. Experiments in Physics, Physics 202, by Paul A Bender and J. Thomas Dickinson. Star Publishing Company (Belmont, CA: 1985). Material taken verbatim.

2. A Survey of Laboratory Physics, Part 2, by Paul A Bender. Star Publishing Company (Belmont, CA: 1984). Material taken verbatim.

Lab 7 Lenses and Optical Devices

Apparatus List

Per Person

3 ea. strips of black construction paper
1 ea. ray box
1 ea. mask set (image and 3 slits)
1 ea. box of six lenses (3 diverging & 3 converging)
1 ea. projection card (11cm x 11.5cm) (white on one side, graph on the other)
1 ea. large binder clip (to hold card)
1 ea. aperature mask
1 ea. red light desk lamp
1 ea. student´s telemicroscope kit
1 ea. ruler

Per Lab

1 ea. pack of white paper
1 ea. optics demonstration box
1 ea. fixed focus camera with wax paper screen
1 ea. nearsighted glasses
1 ea. farsighted glasses
1 ea. `find your height´ mirror demonstration
1 ea. reflecting telescope
1 ea. blackboard optics set-up (from lecture prep)
1 ea. polarization spacer
1 ea. box of mica
1 ea. box of iceland spar (calcite)
1 ea. polarization light table/and demo items
1 ea. large lab jack
1 ea. single filament light source (25w)

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

TA Notes Lab 1

1. At the beginning of class you will need to introduce the concept of motion. In the introductory talk you should illustrate that all of us refer to motion in our daily conversations.

2. Part of the introductory material should include the "Feather and Farthing" free fall demonstration (a penny and a feather in an evacuated tube). Be creative in your introduction of the demonstration. Do not give an explanation of why the behavior is such; let the students develop their own understanding of what is occurring.

3. You will also need to introduce the rudiments of graph making. Particularly the art of sketching based on one´s observations. See attached material for a handout on graphing.

4. a. Part I of the lab will require close supervision. You should move from table to table, checking to see if the students are arriving at the appropriate responses to the questions. You should not just look at the written answer but rather ask the student to verbalize what they have written. For groups larger than twelve people, you may want to arrange for assistance. You will need to make sure that you observe and question each student to help them develop a full understanding of the material.

   b. Do not let the students get bogged down in mathematics and graph drawing. The students are only asked to make sketches, not detailed analysis. The main thrust is for the students to compare graphs and make decisions based on their comparisons.

5. Part II of the lab is much like the 101 lab of the same name. However the students here are not going into the analysis, rather they are again making comparisons and judgments. The graphing ability is at the 101 level. Help the students understand that the graph and its mathematical analysis is simply a tool to further understanding.

6. Part III is optional. The students at this stage are learning how to approach a problem and answer it based on their experimental evidence. Again have the students verbalize their answers.

7. The physics feats are introduced as brain fodder for the students. The intention is for the student to extend his/her knowledge about the use of physics.

8. The lab, as written, is designed for the students to work in a two-person group. You may at times find it easier to cover some of the material as a class using inquiry methods. For example Part I could be done with the whole group. Use good questioning strategies to bring out the desired responses.

Additional Suggestions:

1. Included in the attached material is an inquiry lesson that deals with the independence of gravitational acceleration and mass that can be substituted for the "Feather & Farthing" demonstration. However note that it brings in Force and Newton´s Law concepts that are ahead of the students in lecture.

2. An alternative to using an air track is to get a board and soup can. Start the soup can rolling on the board (you may need to elevate the board a bit). Carry out the same measurements and analysis.

3. Additional suggestions for optional Part III: "Pull the pendulum to one side and let it go. What happens to the amplitude as it swings back & forth? Why?"

You will find a key to one of the service shafts on 3rd floor (room 350). The pendulum is hung from the ceiling of 12th floor; it serves as an illustration of the effect of length on the period.

Graphs

A graph is convenient way to arrange data so that relationships between two or more "properties" (called variables by scientists) can be seen at a glance. The graph will show you how a change in one variable is related to a change in the other. The independent variable is usually graphed on the horizontal axis. It´s value is specified in advance. The dependent variable is the thing we are interested in measuring. It is usually graphed on the vertical axis.

To draw a graph, first decide which is the dependent variable, and plot it on the vertical axis. Plot the independent variable on the horizontal axis. Label the axis to tell what you are measuring. Include the units you are measuring in; there might be a big difference between time (sec.) and time(min.)! Next, determine the scale. You can approximate it by dividing the number of grid lines by the highest data value. This will spread the data points out so you can see the changes easily. Always start with zero at the origin, and use equal intervals or units along the scale. Use different symbols for points and lines representing different experiments, and clearly label which is which. Include a title. Refer to Figure 6.

An important value that can be found from a graph is its slope. The slope is the ratio of changes in the dependent variable to changes in the independent variable. The slope is sometimes called "rise over run" (how fast the curve rises divided by how fast it spreads out [the run]).

Expressing the slope in terms of an equation, we have for the slope, S;

$$S = \frac{\text{rise}}{\text{run}} = \frac{y_2 - y_1}{x_2 - x_1} ,$$

where y_2, y_1 are two values of the dependent variable; x_2, x_1 are the two associated values of the independent variable.

Reading a graph is easy, if everything is labelled. For example, suppose we wanted to know how quickly a mug of fresh hot coffee (Mug A) will cool to room temperature (15° C) if it is left on the table. We are comparing change in temperature (the dependent variable) as a function of time (the independent variable). We decided arbitrarily that time would be measured at 2-minute intervals. You would find the graph to look like graph A. Notice how the line slopes down, indicating that the coffee lost heat with time. When a quantity is measured against time the slope of the line is called the rate.

If we put another mug of coffee (Mug B) in the refrigerator to cool, we could compare their relative rates of cooling. By looking at graph B, we can see that the coffee that was in the refrigerator also lost heat with time (because the graph slopes down), but it reached room temperature sooner. Thus, from these graphs we could quickly determine that both mugs lost heat, but Mug B lost heat at a faster rate (because the slope is steeper). From the graph we could ask questions like: Why did the graph level out at 15° C in A? What was the temperature of the refrigerator? How would the graph look if the mugs contained ice water (0° C) instead of coffee? How long did Mug B take to reach 15° C? Mug A? The slope can be used to answer these questions!!

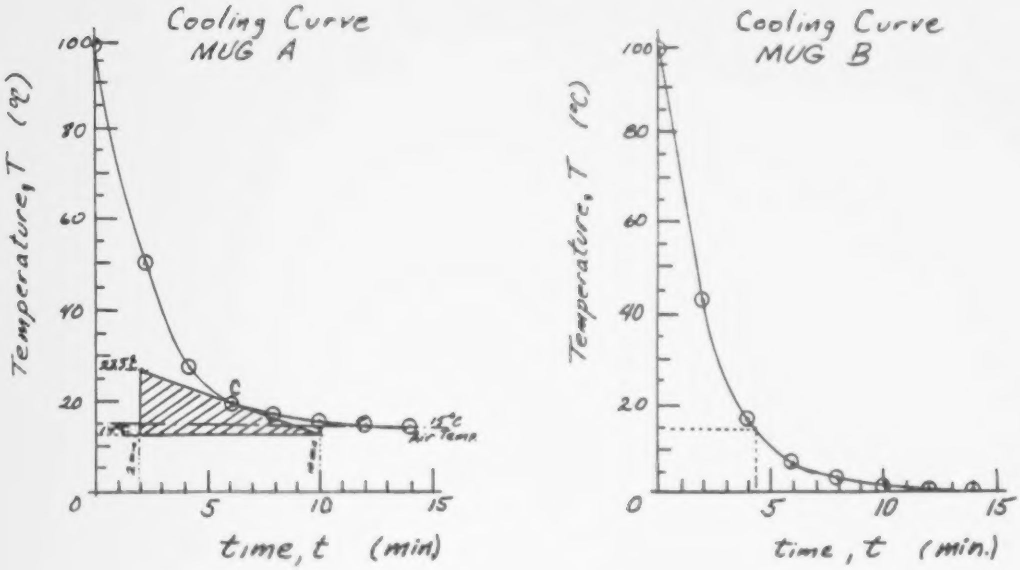


Fig. 1. Graphs of a cooling curve

Referring to the graph for Mug A, you can see a triangle drawn tangent to the curve at point C. The corners of the triangle will be used to find the slope at C. The slope is given by:

$$S = \frac{\text{rise}}{\text{run}} = \frac{T_2 - T_1}{t_2 - t_1} \quad .$$

The size of the triangle run is chosen large for easier reading of the corners but all sizes have the same slope.

From the Mug A graph we have,

$$S = \frac{14^{\circ}\text{C} - 27.5^{\circ}\text{C}}{10 \text{ min} - 2 \text{ min}} = \frac{-13.5^{\circ}\text{C}}{8 \text{ min}} = -1.7^{\circ}\text{C/min. at } t = 6 \text{ min.}$$

Note that the slope varies with time but is pretty constant in the first 2 minutes.

The slope tells us quite a bit. First the (`-´) indicates that Mug A is <u>losing</u> heat (it is cooling). Second, since we have a <u>value</u> versus time, the slope gives us the <u>rate</u> of cooling --- -1.7°C/min. at 6 min. If we had done a <u>graph</u> of distance vs. time or velocity vs. time the slope would again give rates - rates with special names such as speed or acceleration respectively.

Summary of Procedure for Plotting Graphs:

1. Allow plenty of space for the graph.
2. Draw the axis. The vertical or y-axis is called the ordinate; the horizontal or x-axis is called the abscissa.
3. Determine which type of data to plot on each axis. Normally the dependent variable is plotted on the vertical axis and the independent variable is plotted on the horizontal axis.
4. Determine how to display numerical quantities along each axis:
   (a) It is not necessary to start at zero.
   (b) Numerical intervals on one axis need not be the same as on the other axis.
   (c) Intervals should be selected to be of a convenient size for ease of plotting and graph interpretation.
5. Label each axis clearly with the type of data being plotted and the units being used.
6. Plot the points.
7. Draw the straight line or curve which best represents the plotted points.
8. Interpret the graph - estimate slopes when meaningful.

Purpose: The goal of this lesson is for the student to have a clear understanding of the independence of gravitational acceleration, g, and mass.

Rationale: The concept of the constancy of g for all masses is central to solving many basic physics problem. A clear understanding of the concept is required to interpret a physical problem.

Performance Objectives:

Given a word problem dealing with mass, gravity, and air resistance the student will give the correct response using the results of this lesson.

Given several verbal questions on mass and gravity the student will respond that "g" is independent of mass each time.

Content: Gravitational acceleration is independent of mass.

Procedure:

The lesson development flows as follows:

(1) Present an experiment. Questions ensue. The experiment is done. Summarize through student feedback.

(2) Vary experiment. Questions ensue. The experiment is done. Summarize through student feedback.

(3) Vary experiment. Questions ensue. The experiment is done. Summarize through student feedback. (This last experiment branches to a new topic.)

The sequence of the lesson is such:

(1) Focuser - World Series, Baseball, and falling objects.

weight

mass - the quantity of matter in a body. More specifically, it is the measurement of the inertia or

Q1 - What makes a baseball fall?

response - force of gravity

Q2 - Does it make a difference how much it weighs?

response - in air, yes - in vacuum, no

Define on overhead weight and mass

(2) Procedure

(a) Introduce experiment (2 balls, 1 lead, 1 regular)

Q3 - If I release these balls at the same time, which will hit first?

Generate a general response. Each student indicates choice.

DO IT

Q4 - What can you conclude about the effect of the different weights (amount of mass) on how the balls fell.

Student response and indicate why they made that choice.

Differentiate between mass and <u>weight</u>

(b) Experiment 2 (2 different sized balls)

Q5 - Does size have an effect?

Generate a group response.

DO IT.

Q6 - So, what is the important factor?

Generalize response.

(c) Experiment 3 (Paper and ball)

Q7 - Which will hit first?

After response crumple paper and drop it.

Q8 - So, what is the important factor? Why?

Generate response. Evaluate by leading them into trying it with paper not crumpled.

(d) Thought experiment

Q9 - What would´ve happened in a vacuum?

Have them support their answer by citing parts of Experiment 3.

Extension of

(1) Focuser - So we´ve decided that the weight (mass) has no bearing on the fellow but air resistance does so..

(2) Let´s look at Newton´s Laws....

We know that a falling body

$F_{net} = ma$ and inertia

the `weight´ of an object is given by $F_g = mg$

A body falling is described by

$F_{net} = F_a + mg$ net force where F_a is force of air resistance but we can ignore F_a (in our earlier exp.)

so, $F_{net} = mg$ but $F_{net} = ma$

$$a = \frac{F}{m}net$$

$a = \frac{F}{m}net = \frac{mg}{m}$ $g = \frac{F}{m}net$ ratio of weight to mass

$a = g$

Same for all bodies in the same locale

$\frac{F}{M}net = g$ $\frac{f}{m}net = g$

Much like

$\frac{C}{D} =$ $\frac{c}{d} =$

The kicker is air resistance

so $F_{net} = F_a + mg$ when in vector form - Now F_a depends on the speed through the air. The faster it goes the larger F_a will be until -

mg

$F_a = mg$ or if you like $mg - F_a = 0$

which means the object has no net force and thus no acceleration

What you see is

Paper

terminal velocity

since $\frac{v}{t} = a$ by definition

So the net force is zero, so it moves at a constant velocity!

For calc buffs $a = \frac{v}{t}$ so if $\frac{v}{t} = 0 =$ $v = 0$ then V is as constant in time.

Interject parachuters

Interject extension

(3) Closure. Draw a group summary. Stress importances. Suggest they extend air resistence in their own experience.

(4) Evaluation Procedures: Following the closure give them attached question sheet. This is a small summative check. Formative check is continuous.

Lesson Extension: Develop the mathematics to back-up our observations.

Materials: 2 tennis balls (1 filled with lead shot), 1 ping pong ball, 1 basketball, 2 sheets of paper, 1 observation sheet per 2 people, 1 question sheet per person, overhead.

1. If you repeat todays experiments on the moon, what would you notice different?

2. Clearly distinguish between mass and weight.

3. Suppose an elephant and a feather fall from a high tree, which encounters the greatest force of air resistance in falling to the ground.

a) the elephant   b) the feather   c) both the same

Justify your answer

(Note - Elephant clearly the largest - largest frontal area. But importance is Fa/m; Here the feather is largest so it reaches terminal velocity quicker).

4. A boulder is many times heavier than a pebble - that is, gravitational force that acts on a boulder is many times that which acts on the pebble. Yet if you drop a boulder and a pebble at the same time, they will fall together with equal accelerations (neglecting air resistance). The principal reason the heavier boulder doesn´t accelerate more than the pebble has to do with:

   a) energy b) weight c) inertia d) surface area
   e) none of these

   Justify your answer.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

TA Notes Lab 2*

TREE FORCE

NEEDED: Observation.

The roots of a growing tree can exert unbelievable force. They can destroy concrete foundations and create massive upheavals of earth and rock. They can split a hard rock if growing inside it.

In the drawing a tree growing in a front yard is seen destroying concrete steps, the walk, and the street curb.

The large force exhibited by the roots is the combined forces of millions of tiny cells with fragile walls.

But there is very little energy involved. Energy or work equals force times distance moved. Power equals energy over time. Distance moved is small, energy small, time long (large), power small.

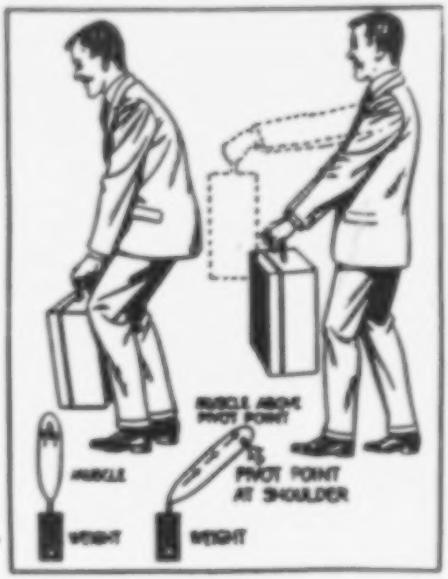
YOU AND A HORSE

NEEDED: A ruler, a scratch pad, a pencil.
EXPERIMENT: Measure the height of the stairs or steps, then find out how much energy is used in climbing them.
METHOD: Multiply the height by your weight to get foot-pounds of energy. Suppose you weigh 110 pounds and the stair is ten feet high, you have used 1110 foot-pounds of energy. To change this into horsepower, another figure must be added: time. Horsepower is 33,000 foot-pounds per minute, or 550 foot-pounds per second. If you climb the stairs in five seconds, then your power is 11-- divided by five times 550, or four-tenths of a horsepower.

WEIGHT LIFTING

NEEDED: A weight.

EXPERIMENT: Lift the weight as in the drawing at left, and it is easy. Try to lift it as shown in the drawing at right, and it is difficult or impossible.



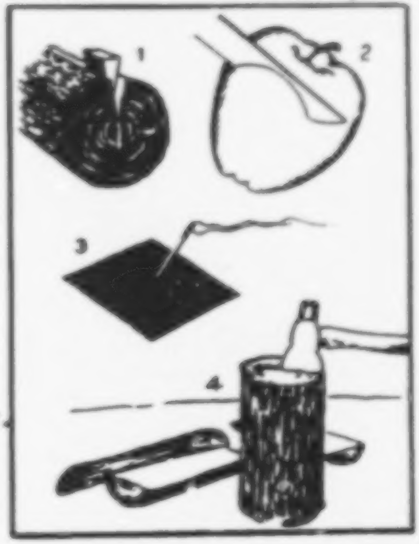
REASON: In the left drawing, the muscle tension (force upward) and the weight act along the same line and are equal. Both are fairly small.

In the right drawing, where the arm is extended, the muscle tension times its distance from the pivot point must equal the weight times its distance from the pivot point (length of arm). Since the weight is far from the pivot point and the muscle close to the pivot point, the muscle tension must be many times the weight, if it is to support the weight.

The lower drawings show this in an over-simplified manner. The pivot point is the shoulder joint.

GLAMORIZING THE WEDGE

DICTIONARY DEFINITION: A wedge is a piece of wood or metal, small at one end and larger at the other, used for rending or compressing.



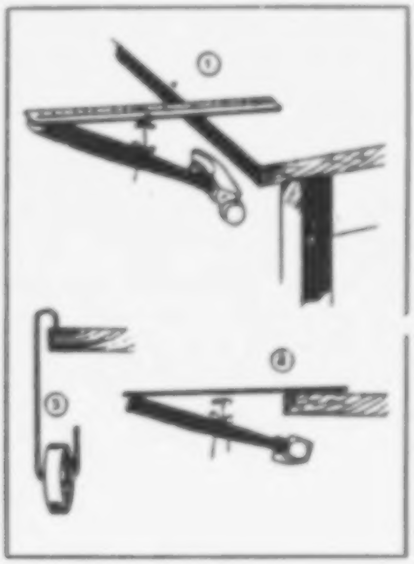
COMMENT: A wedge is a type of inclined plane which is pushed into an object to cut or split it. The smaller the angle of the wedge, the easier it is to cut the object; therefore a sharp knife cuts better than a dull one.

The push required to move a wedge into an object is not easy to determine because of friction.

The wedge is used by carpenters and woodsmen in the form of the ax, chisel, plane, and nail. The farmer turns his soil with a wedge--the plow. A rotating wedge or cam is used to push up the valve rods in automobile engines. A needle is a wedge, too.

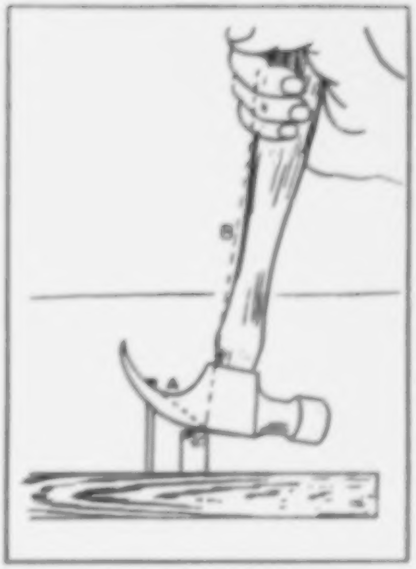
DEFYING GRAVITY

NEEDED: A hammer, a ruler, a string a table edge.
EXPERIMENT: Tie the ruler and hammer together as shown, and they will hang from the table in what will look like a most precarious manner.
REASON: Most of the weight is in the hammer head, and if the ruler is moved along the table edge until the center of weight of the assembly is directly under the edge, the balance point will be easy to find. It is as if the weight were hanging straight down from the table. The center of gravity of the assembly must be on the table side of the table edge.



MULTIPLIED MUSCLE POWER

NEEDED: A hammer and a nail, a piece of wood, a small block of wood.
EXPERIMENT: Try pulling the nail with the nose of the hammer against the wood. Then place the small block under the hammer as shown, and the nail will be pulled easily.



REASON: Note the two broken lines in the drawing. If the distance of line A is one inch, and the distance of line B is 10 inches, the pull on the handle places about ten times as much pull on the nail. If 40 pounds of pull is exerted on the handle, about 400 pounds of pull is exerted on the nail. The pulling force applied to the handle will most ten times as far as the nail moves.

The hammer is a form of lever.

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*From: 333 Science Tricks & Experiments, by Robert J. Brown, Radio Shack, Cat. No. 62-1081.

PHYSICAL SCIENCE FOR ELEMENTARY EDUCATION TEACHERS
PHYSICS BLOCK

T.A. Notes Lab 4 -- Behavior of Gasses

Equipment Notes

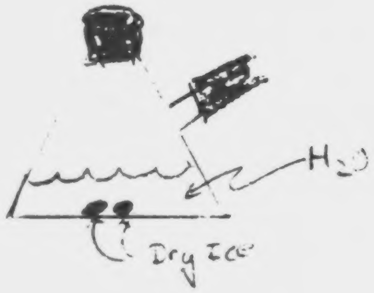
1. Note that the equipment is different from that indicated in the instructions. The scale is now on the plunger, not on the body of the syringe, and no longer calibrated. Students will have to calibrate the scale in cm3, finding the zero volume reading and calculating the volume from the inside diameter of the syringe body and the scale reading. A good way to read the scale is to sight across the top of the syringe body, being careful to eliminate parallax.

2. The pistons or plungers should be snug, but not tight, in the syringe body. If necessary, try a little spray lubricant (not vasoline; it sets up hard after a few days). Please spray into a cardboard box or into the waste basket. Much of that stuff on the floor makes it as slippery as ice. If the plungers stick, twist slightly.

3. At the end of lab remove all the pistons from their syringes so they don't freeze in place.

4. Make a CO2 "generator" to fill the syringes, as shown below.

5. Put weights on the plunger slowly, both to prevent large temperature changes and to prevent overturning the apparatus.



Demonstrations

1. Liquification of dry ice (to be done by TA's only): Using the special syringe on the front desk (not the syringes at the student desks) a little (pea size) piece of dry ice can be liquified by hand pressure. If the plunger is then released solid CO2 will form. The plunger will also travel the length of the lab so aim carefully!

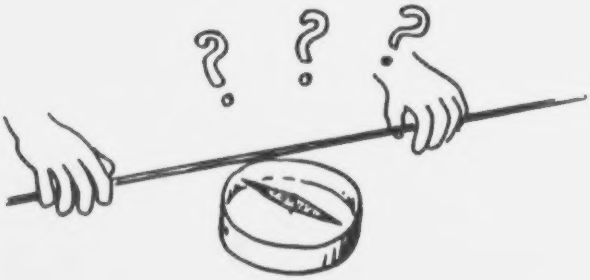
BE SURE GAS STOPCOCKS ARE OFF WHEN DONE!!

TA Notes -- Lab 6

CURRENT AND COMPASS

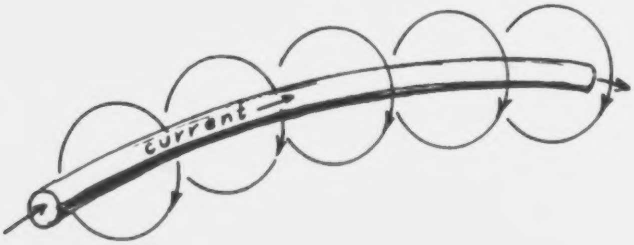
If a current-carrying wire runs directly over a magnetic compass, the needle of the compass will

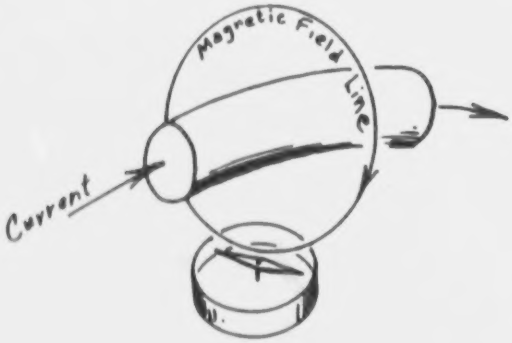
a) not be affected by the current
b) point in a direction perpendicular to the wire
c) point in a direction parallel to the wire
d) tend to point directly to the wire



ANSWER: CURRENT AND COMPASS

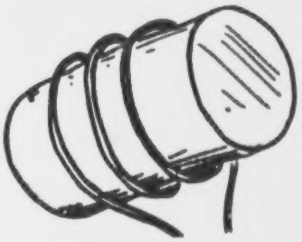
The answer is: b. The magnetic field lines circle the current in the wire as shown. The needle of the compass then orients itself parallel to and along the magnetic field lines. Therefore the needle is perpendicular to the current.





FARADAY´S PARADOX

This is a coil of wire with a hunk of iron locked in it.



This is a coil of
wire with a hunk
of iron locked in it.

a) If current is made to flow in the wire, the iron becomes a magnet
b) If the iron is a magnet, current is made to flow in the wire
c) Both of the first two statements are true
d) Both of the first two statements are false

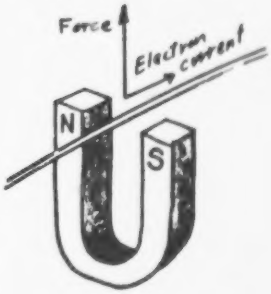
ANSWER: FARADAY´S PARADOX

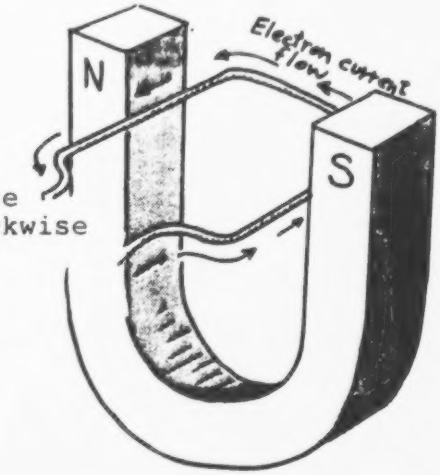
The answer is: If current flows in a wire wrapped around some iron (say a nail), it becomes an electromagnet. Making such a magnet is an old standard Cub Scout project. But if a magnet is sitting inside a coil it does not cause a current in the coil or even charge the wires. In the days of Queen Victoria, Michael Faraday* and many of his contemporaries puzzled about this. They thought if current makes magnetism, then by all rights magnetism should make current, but how? While wondering about this, Michael Faraday made his big discovery. A magnet would make a current in the coil, but only if it was moved inside the coil and not locked in one place. After all, it takes energy to make a current and the energy comes from the force that moves the magnet or the coil.

Faraday´s discovery was the key to electric generators. A generator just moves a magnet back and forth near a coil (or moves a coil near a magnet) and so makes an electric current flow in the wire. The Prime Minister of England came to Faraday´s laboratory to actually see electricity generated in this way. After the demonstration he asked Faraday, "What good is electricity?" Faraday answered that he did not know what good it was, but that he did know some day the Prime Minister would put a tax on it!

METER TO MOTOR

When electrons in a wire flow through a magnetic field in the direction shown, the wire is forced upward. If the current is reversed, the wire is forced downward. If a wire loop is instead placed in the magnetic field and the electrons flow in the direction shown below, the loop will tend to

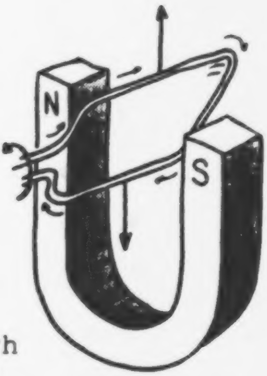


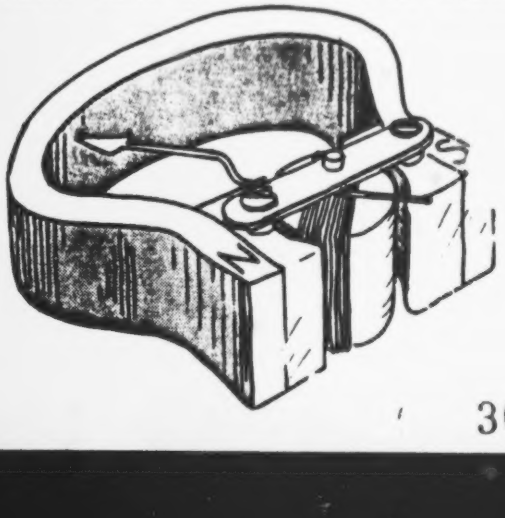


a) rotate clockwise
b) rotate anticlockwise
c) do nothing

ANSWER: METER TO MOTOR

The answer is: b, for the right side is forced up while the left side is forced down as shown. Although this is an easy question to answer, its point is important for this is how electric meters work. Instead of one loop, many loops forming a coil are used, and held by means of a spring. When current is made to flow through the coil the resulting forces twist the coil against the spring -- the greater the current, the more the twist, which is indicated by a pointer that gives the reading. It is only one step further to an electric motor, wherein the current is made to change direction with each half turn of the coil so that it turns repeatedly.





Underlying electric meters and motors is the simple fact that electric current is deflected in a magnetic field. The deflecting force is always perpendicular to both the current and the magnetic field as shown in the sketch.

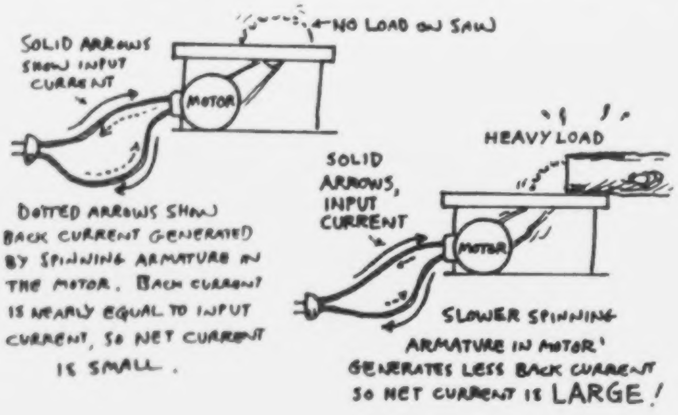
MOTOR-GENERATOR

Both an electric motor and a generator consist of coils of wire on a rotor that can spin in a magnetic field. The basic difference between the two is whether electric energy is the input and mechanical energy the output (a motor), or mechanical energy is the input and electric energy the output (a generator). Now current is generated when the rotor is made to spin either by mechanical or electric energy -- it needn´t "care" what makes it spin. So is a motor also a generator when it is running?

a) Yes, it will send an electric energy output through the input lines and back to the source
b) It would if it weren´t designed with an internal bypass circuit to prevent this problem
c) No, the device is either a motor or a generator -- to be both at the same time would violate energy conservation

ANSWER: MOTOR-GENERATOR

The answer is: a. Every electric motor is also a generator, and in fact, the power company that supplies the input energy in effect gives you a refund for the energy you send back to them. That´s because you pay for the net current and hence the net energy consumed. If you motor is spinning freely with no external load it will generate almost as much current as it is powered with, so the net current in the motor is very little. Your electric bill is low as a result. The back current, not friction, limits the speed of a free-running motor. When the back current cancels the forward current, the motor can spin no faster. But when your motor is connected to a load and work is done, more current and more energy is drawn from the input lines than is generated back into them. If the load is too great the motor may overheat. If you go to the extreme and put too great a load on a motor such as to prevent it from spinning -- like jamming a circular saw in stubborn lumber for example -- no back current is generated and the undiminished input current in the motor may be enough to melt the insulation in the motor windings and burn the motor out!


NO LOAD ON SAW
SOLID ARROWS SHOW INPUT CURRENT
MOTOR
DOTTED ARROWS SHOW BACK CURRENT GENERATED BY SPINNING ARMATURE IN THE MOTOR. BACK CURRENT IS NEARLY EQUAL TO INPUT CURRENT, SO NET CURRENT IS SMALL.
HEAVY LOAD
SOLID ARROWS, INPUT CURRENT
MOTOR
SLOWER SPINNING ARMATURE IN MOTOR' GENERATES LESS BACK CURRENT SO NET CURRENT IS LARGE!

From Thinking Physics by Lewis Epstein. Insight Press (San Francisco: 1983).

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK

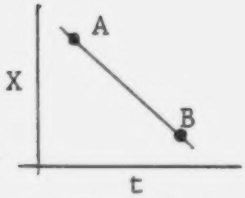
HOMEWORK PROBLEM SET #1

1. If the stick of "Measurements, Fig. 1" is found to be 50 cm long and the distance from A to B is found to be 14.6 stick lengths, then what is the distance from A to B in meters?

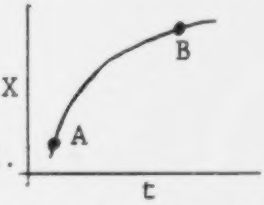
2. How many kiloseconds are there in an hour? How many minutes are there in one kilosecond?

3. Graphs for position versus time are shown below.
    A. State whether they indicate constant or changing velocity.
    B. Is the average velocity in the interval A-B positive, zero, or negative for each case?

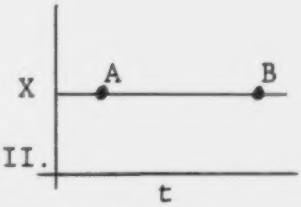
I.



II.



III.



4. A driver traveling to Moscow (a distance of 8 miles) averages 30 miles/hour for the first four miles. How fast must she drive to average 60 miles/hour for the total trip?

5. Two drag racers are given the go flag. The red car's engine starts 1/2 second later and then accelerates at 5m/s^2. The blue car has a good start and takes off immediately at 4 m/s^2. After 3 seconds from the go flag which car has gone the farthest? Which car has the largest velocity?

6. For the situation of problem 5 answer the questions for 5 seconds after the go flag.

7. K&F #1-4 - A car accelerates from a speed of zero to 60 km/hour in 12 s. What is its acceleration?

8. K&F #1-7 - At the end of its arc, the speed of a pendulum is zero. Is its acceleration also zero?

9. A ball is thrown up at an angle of 45° with respect to the ground, describe how the X and Y components of its velocity vary as it travels. Continue the discussion until the ball strikes the ground.

10. Discuss the forces acting on the ball of problem 9 during this motion, including the forces to start and stop it.

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK

HOMEWORK PROBLEM SET #2

1. A child in a city where the blocks are square starts from the corner of West Third Avenue and North Second Street, and walks south 5 blocks along West Third Avenue, crossing Main Street and reaching South Third Street. She then walks 5 blocks eastward, crossing Center Avenue to reach East Second Avenue. She then runs to the corner of North First Street and East Second Avenue, and finally she goes along North First Street to West Fourth Avenue.

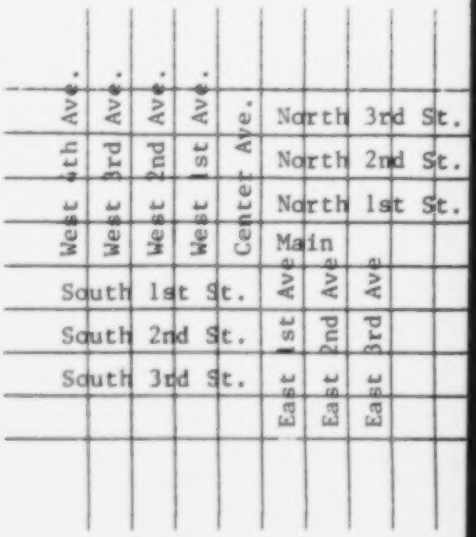

West 4th Ave.
West 3rd Ave.
West 2nd Ave.
West 1st Ave.
Center Ave.
North 3rd St.
North 2nd St.
North 1st St.
Main
South 1st St.
South 2nd St.
South 3rd St.
East 1st Ave
East 2nd Ave
East 3rd Ave

Figure 1

a. What is the distance traveled?

b. What is the displacement for the entire trip?

displacement = vector position
distance traveled = total length of all segments of trip

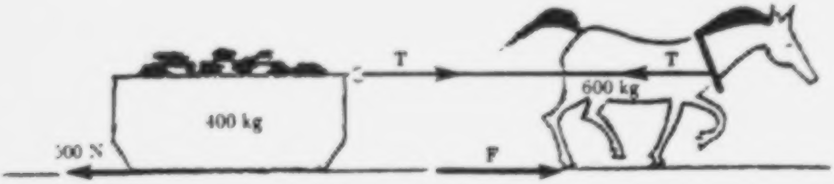

T
T
600 kg
400 kg
500 N
F

Figure 2

2. A horse is pulling a heavy cart, and the cart (and horse) are both being accelerated. Is the force of the cart on the horse equal and opposite to that of the horse on the cart? If your answer is "yes," explain how it is that these equal and opposite forces give rise to the "net force" that is necessary to cause acceleration. If your answer is "no," explain whether Newton's third law is true while the cart is accelerating.
   Explain how the horse becomes accelerated. What is the origin of the "net force" on him? In which direction is the net force on the horse?

3. A horse of mass 600 kg is setting into motion a loaded stoneboat of mass 400 kg (Figure 2). The force of friction is 500 N.

   a. What forward force F is exerted on the horse by the ground if the system has a forward acceleration of $2ms^{-2}$? (Hint: Consider the whole system in solving this part of the problem.)

   b. What is the tension in the connecting rope? (Hint: Consider either the horse or the stoneboat for this part, as a check, do it both ways.)

4. If you push vigorously against a brick wall, how much work do you do on the wall?

5. When a punter kicks a football, is he doing any work on the ball while his toe is in contact with the ball? Is he doing any work on the ball after it loses contact with his toe?

6. A football player leaps into the air to catch a forward pass. Discuss the catch in terms of both the conservation of momentum and the conservation of energy.

7. What is the weight in newtons of a man whose mass is 70 kilograms?

8. What is the mass of a child whose weight is 300 N?

9. The motor on a 75 kg moped exerts a forward force on the bike of 300 newtons. Find the acceleration of the moped.

10. How much potential energy does a 60 kg high jumper have when he/she goes over a 2 meter bar?

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK

HOMEWORK SET #3
(Not to be turned in)

Rotational

1. A penny is laid on the rough surface of a phonograph turntable, near the outer edge, and the motor is turned on. The penny does not slip, and it turns with the turntable with a constant speed of 33 1/3 rev/min. Is the velocity constant? Is the penny in equilibrium?

2. Is it possible for a body to be accelerated if its speed is constant?

3. Consider an atom of aluminum near the rim of a phonograph turntable turning at 45 rev/min. Does any centripetal force act on the atom? If so, what is this force caused by?

4. What is the source of the centripetal force on the pilot of a plane that is executing a vertical loop-the-loop, when the plane is at the bottom of the loop, curving upward?

5. Often when a high diver wants to turn a flip in mid-air, she will draw her legs up against her chest. Why does this make her rotate faster? What should she do when she wants to come out of her flip?

6. As a tether ball winds around a pole, what happens to the speed of the ball? Why?

Heat

7. Markings to indicate length are placed on a steel tape in a room which has a temperature of 22° Celsius. A surveyor uses the tape on a day when the temperature is 27° C. If he measures the width of a lot to be 30 meters, is his measurement too long, too short, or accurate? Defend your answer.

8. One hundred grams of ice is at 0° Celsius. How many calories of heat are required to change all of this to steam?

9. Give examples to distinguish between temperature and heat.

10. What would happen if the glass of a thermometer expanded more upon heating than did the liquid inside?

11. Why can potatoes be baked more quickly by putting a piece of metal through them?

12. Suppose you are outside on a below-freezing day. Why would it be more dangerous to lick a steel pole than a piece of wood?

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK

HOMEWORK PROBLEM SET #4

1. A rod with a positive charge is brought near, but not touching, an electroscope. Its foil stands out. Why? What kind of charge is on the foil?

2. A rod with a positive charge is brought near, but not touching, an electroscope. When we remove our finger and the positively charged object, does the foil move? Why? What kind of charge is on the foil?

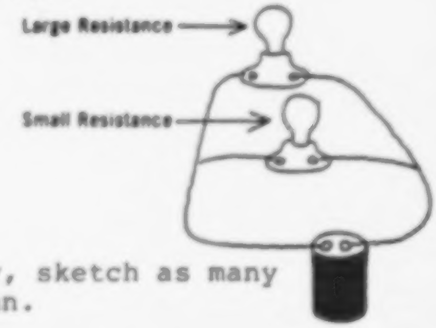
3. Two objects are charged: one positive, the other negative. What happens when they touch?

4. Assume you have a solid metal ball and a hollow ball of the same size and material. Which one can you place the most charge on? Why?

5. A charged comb often will attract small bits of dry paper which fly away when they touch the comb. Why?

6. You need a 27 volt battery but all you have is a box of several 1.5 volt batteries. Sketch a circuit that would enable you to get your 27 volts from them.

7. The figure to the right illustrates two resistances - one large and one small - connected to a battery. In which resistor is the current largest? Why? Which resistor has the most voltage across it? Why?



8. Given three light bulbs and a battery, sketch as many different electric circuits as you can.

9. Discuss the changes in energy that occur as a charge moves through a circuit.

10. A wire carries a current from south to north. If a compass is placed above the wire, will it deflect in the same direction as it will when placed below the wire? Explain.

11. Two parallel wires carry electric currents. Do they affect each other? Why?

12. You are an astronaut stranded on a planet with no test equipment or minerals around. The planet doesn't even have a magnetic field. You have two pieces of iron in your possession; one is magnetized, one is not. How could you determine which is magnetized?

13. There are irregular variations in the strength and direction of the earth's field at points on the surface having the same latitude. What could cause these variations?

14. A beam of particles shoots through your dormitory room. If you would like to know whether they are electrically charged, how could a magnetic field resolve your problem?

15. What will be the effect of rotating the coil of a generator at a faster rate?

16. When you hear an electrical device humming, it is likely a transformer producing the sound. What causes transformers to hum? What frequency of hum do you expect from the transformer?

17. Could a current be induced in a coil by rotating a magnet inside the soil?

18. Why will a transformer not work for DC?

19. Propose some experiments that you could do to show that gravity, electricity and magnetism are different phenomena, and discuss the conclusions they provide.

PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK

HOMEWORK PROBLEM SET #5
(Not Due)

1. How long must a mirror be in order that a person 2 meters tall can see his whole image (standing) in the mirror? (Be careful - the answer is not 2 meters.)

2. Suppose you are told only that two colors of light (X and Y) are sent through a prism and that X is bent more by the prism than is Y. Which color travels slowest in the glass of the prism?

3. Is the lens shown in Figure 1 a converging or a diverging lens? Why? Why do you suppose a lens shaped like this is often used in eyeglasses?

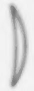


Figure 1

4. Use the law of refraction to convince yourself that the path followed by a ray of light through a pane of glass is as shown by the dark line in Figure 2. What does the gray line show?

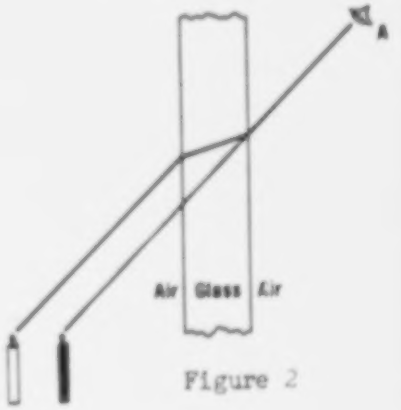
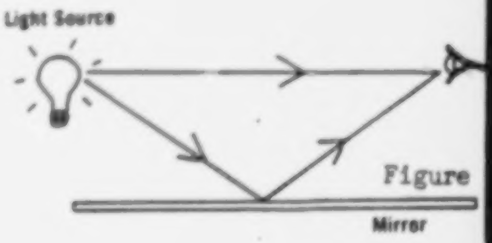


Figure 2

6. Interference patterns can be produced by the two light waves shown in Figure 3. Explain.

7. To reduce the glare from light reflected off water, should polarizing glasses cut off vertically or horizontally polarized light? Explain.



Figure

8. Does the light produced by a neon sign constitute a continuous spectrum or only a few colors? Defend your answer.

9. Which has more energy, a photon of ultra-violet "light" or a photon of yellow light?

10. Refer to Figure 4. Would you expect the energy of the electron to change more or less from n = 1 to n = 2 as compared to n = 2 to n = 3? Why? Is the distance from n = 1 to n = 2 greater or less than the distance from n = 2 to n = 3?

11. 12/6 C and 13/6 C both have 6 protons in the nucleus. 12/6 C and 11/5 B both have six neutrons. The first pair are both the same element, but the second pair are not. Why is the number of protons so much more important then the number of neutrons?

12. Alpha particles emitted with exactly the same energy as beta particles do not penetrate as far. Why?

13. If an element has a half-life of two days, how much of an original sample of two milligrams remains after eight days?

P

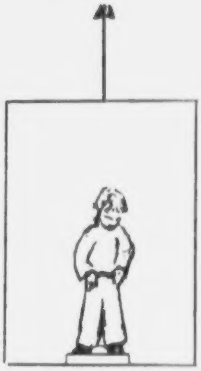
PHYSICAL SCIENCE FOR ELEMENTARY TEACHERS
PHYSICS BLOCK -- EXAM 1
11 April 86

Answer questions on a separate page.

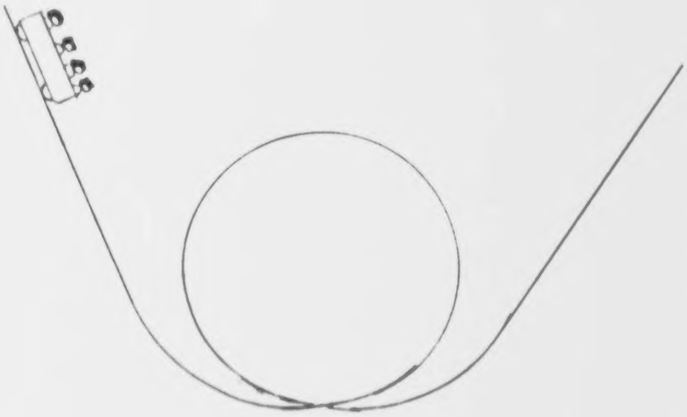
1. 36 pts. -- Define or describe the following concepts. Be brief but complete and clear.
   A. Average Velocity
   B. Acceleration of Gravity
   C. Newtons Second Law
   D. Action-Reaction (Newtons Third Law)
   E. Momentum
   F. Conservation of Energy
   G. Angular Momentum
   H. Temperature
   I. Heat
   J. Heat Capacity
   K. Triple Point
   L. Thermometric Properties

2. 13 pts. -- A basketball player shoots a basket from 20 ft. away from the basket. It´s a high arching shot that drops neatly through the basket for a score. Describe all of the forces on the ball as it is being shot by the player, as it travels to the basket and as it drops through the net. Also describe the motion as the ball travels from the player to the hoop, be sure to indicate the velocity and acceleration at important points in the trajectory such as the point of release. The peak of the path and just before it hits the net.

3. 12 pts. -- A student is standing on a scale in an elevator. The elevator is accelerating at 2 m/s. If the student´s mass is 60 kg, what does the scale read in Newtons?



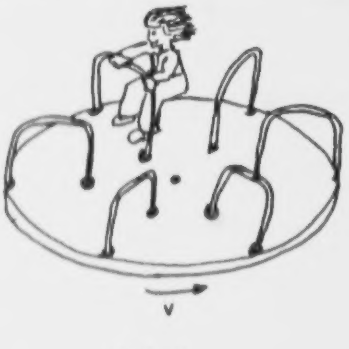
4. 13 pts. -- Consider the amusement park ride below; (Note: The car starts by being lifted to a point on the left side from which it is released. No further energy is provided.)



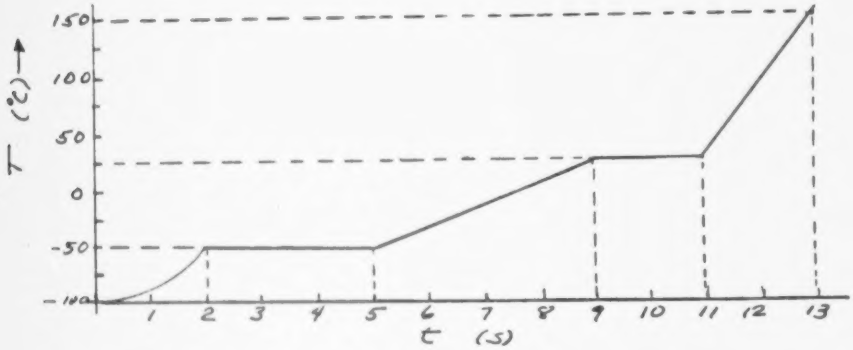
A. Does the car have to start higher than the central loop?
B. Where does the centripetal force on the rider come from at the bottom of the central loop?
C. Where does the centripetal force on the rider come from at the top of the loop?
D. Write down the equation that tells us how fast the riders are going when they are a distance y above the bottom.

5. 13 pts. -- A playground merry-go-round has a flat horizontal disk with a freely rotating bearing at its center. A child pulls him/herself toward the center of the disk.

A. How is the rotational velocity of the merry-go-round affected?
B. How is the angular momentum affected?
C. How is the kinetic energy of rotation affected?
D. Does the child have to work to move toward the center?



6. 13 pts. -- A new substance is being studied, (a 1 g piece), it starts out as a solid at -100C and is warmed by adding heat at the rate of 25 cals/sec. The data below indicate the behavior as it heats and subsequently vaporizes.



A. What is its melting temperature?
B. What is its boiling temperature?
C. How much heat did it require to melt?
D. How much heat is required to raise the liquid phase $1C^{o}$?
E. In what phase is the specific heat the largest?

THE EQUATION SHEET

$$x - x_o = \frac{v + v_o}{2} t$$

$$v - v_o = at$$

$$x - x_o = v_o t + \frac{1}{2} a t^2$$

$$v^2 - v_o^2 = 2a(x - x_o)$$

$$F = ma$$

$$P = mv$$

$$T = Fr_{perp}$$

$$PE_{gravity} = mgy$$

$$KE_{TRANSL} = \frac{1}{2} mv^2$$

$$TE = PE + KE$$

$$T = I\,(a/r)$$

$$L = I\,(v/r)$$

$$KE_{rot} = \frac{1}{2} I\,(v/r)^2$$

$$Q = mc\Delta T$$

$$= m\ell$$

Physics Teaching Resources

A. Books and Publications

1. Refer to the references of each lab write up.

2. Thinking Physics - Gedanken Physics, by Lewis C. Epstein. Insight Press (San Francisco: 1983). Excellent collection of non math physics questions with complete physical explanations. This book will help develop physical understanding.

3. Physics Experiments for Children, by Muriel Mandell. Dover Publications (New York: 1968). Good collection of simple demonstrations using everyday objects.

4. Science Experiments and Amusements for Children, by Charles Vivian. Dover Publications (New York: 1967).

5. The Physics Teacher, journal published by the American Association of Physics Teachers. The journal is designed for high school physics. However many of the topics and demonstrations talked about are applicable to elementary school. Talk to your local physics teacher for ideas.

6. 333 Science Tricks & Experiments, by Robert J. Brown, Radio Shack, Cat. No. 62-1081.

7. Safe and Simple Electrical Experiments, by Rudolf F. Gray. Dover Publications (New York: 1973). Fantastic source of inexpensive science experiments using everyday materials.

8. High school physics texts.

9. Elementary School Science Curriculum Guides

B. Sources of Equipment

1. Contact local businesses, (e.g. optometrist for lenses).

2. Radio Shack for electrical equipment, (e.g. buzzers and switches).

3. Edmund Scientific Company, Barrington, New Jersey 08007.
   Contact them for a catalog. They have many interesting items, (e.g. prisms, lenses, luminous paint).

4. Your local Educational Service District office.

5. Your local high school physics teacher. He/she has many ideas and items that can be of use to you.

6. Local colleges.

7. Current information. Attached are articles and quips that you might find useful.

2. Just after a rock is dropped out of a window, it is in equilibrium. The force which the rock exerts on the earth is equal and opposite to the force which the earth exerts on the rock. Consequently, Newton's third law applies here, and the net force on the rock is zero.

3. An object is thrown vertically into the air. It rises to a maximum height, and then falls again. As it rises, its acceleration is positive, and as it falls, its acceleration is negative. At the maximum height, it is momentarily at rest, and its acceleration is zero.

Notice that all three of these examples are drawn that physics is usually presented as a problem-solving discipline, and students thus have a good deal of practice in solving homework problems in preparation for examinations. However, most students who take introductory physics will not, in the future, be called upon to make calculations. Instead, they will need to make informed evaluations of written statements, both formal and informal. The critical reading and correction of paragraphs containing errors thus has a place both in homework problems and on examinations.

Paul G. Hewitt
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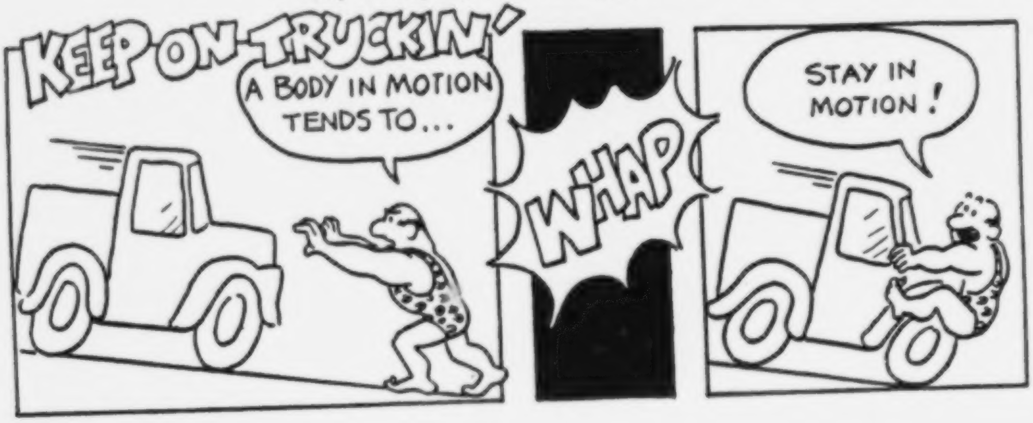
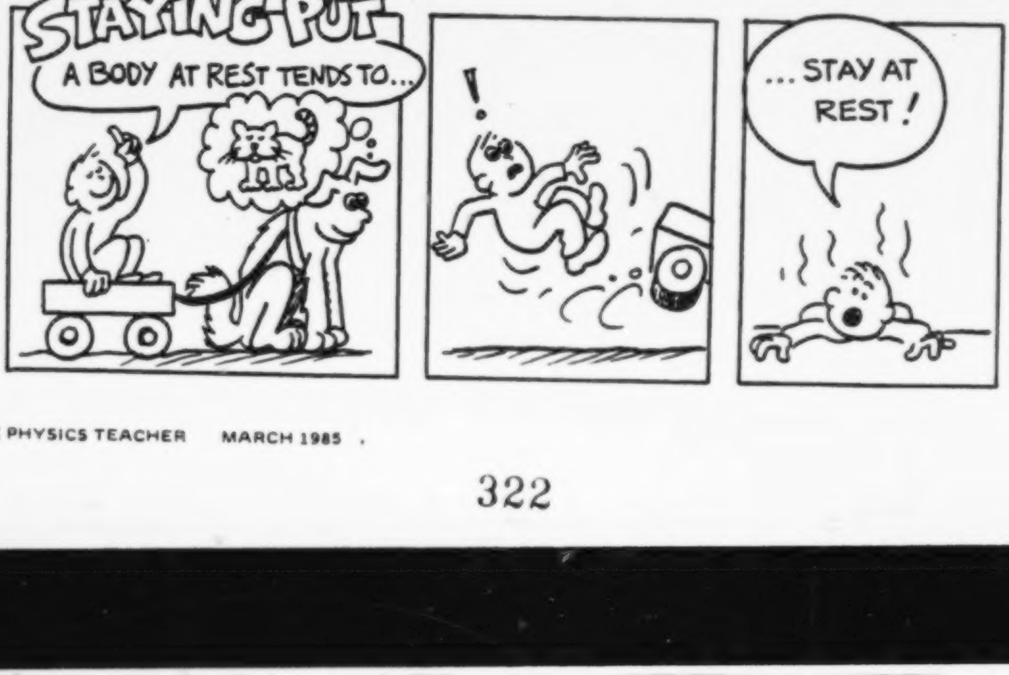
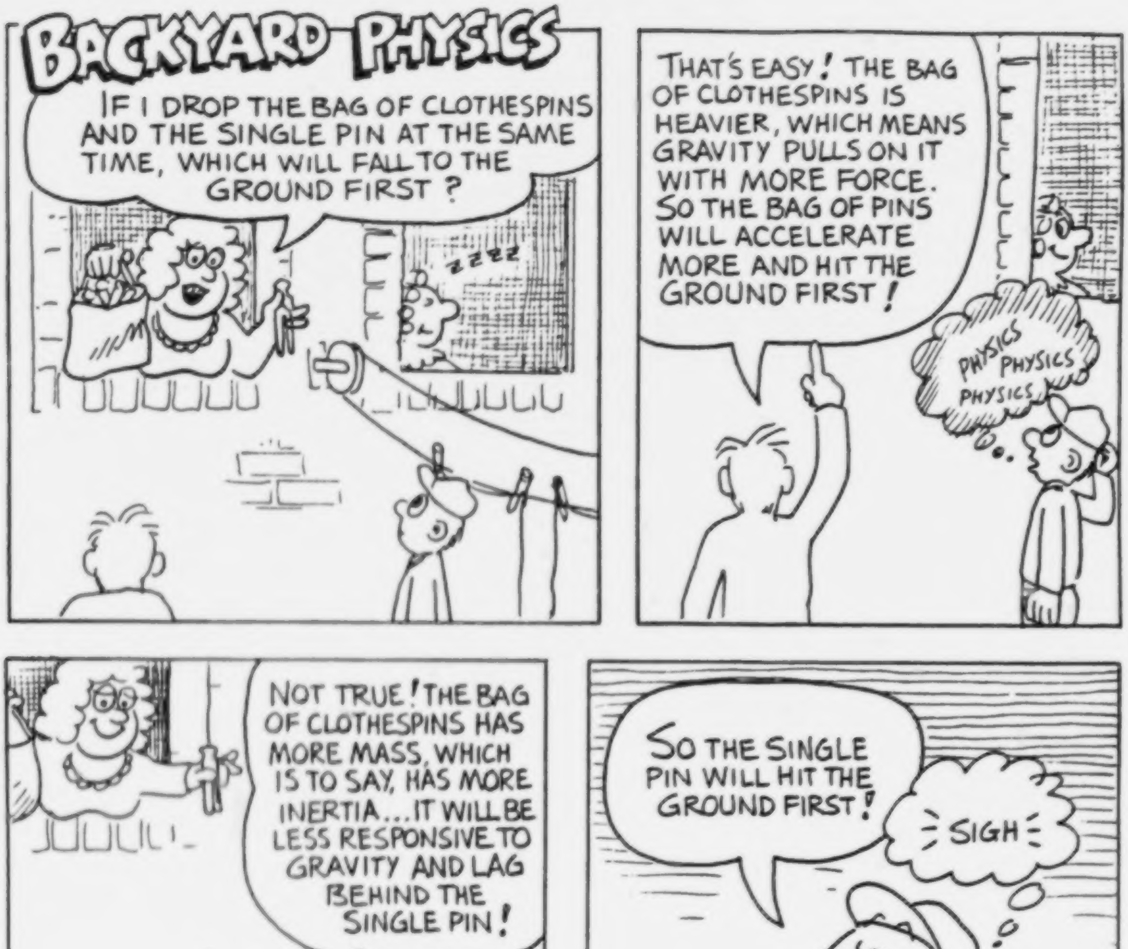
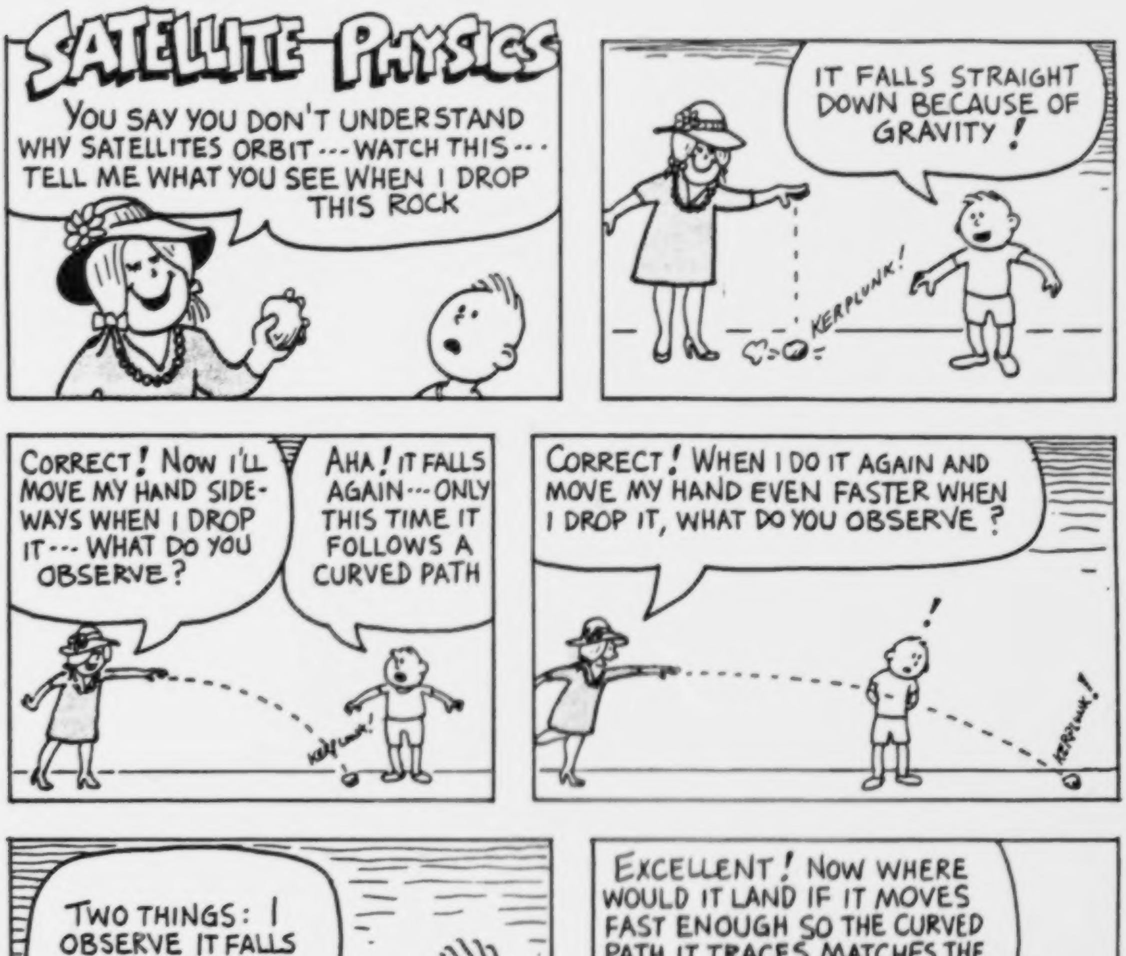

KEEP ON TRUCKIN'
A BODY IN MOTION TENDS TO...
WHAP
STAY IN MOTION!

Paul G. Hewitt
City College of San Francisco, San Francisco, California 94112


STAYING PUT
A BODY AT REST TENDS TO...
!
...STAY AT REST!


BACKYARD PHYSICS
IF I DROP THE BAG OF CLOTHESPINS AND THE SINGLE PIN AT THE SAME TIME, WHICH WILL FALL TO THE GROUND FIRST ?
ZZZZ
THAT'S EASY! THE BAG OF CLOTHESPINS IS HEAVIER, WHICH MEANS GRAVITY PULLS ON IT WITH MORE FORCE. SO THE BAG OF PINS WILL ACCELERATE MORE AND HIT THE GROUND FIRST!
PHYSICS PHYSICS PHYSICS
NOT TRUE! THE BAG OF CLOTHESPINS HAS MORE MASS, WHICH IS TO SAY, HAS MORE INERTIA... IT WILL BE LESS RESPONSIVE TO GRAVITY AND LAG BEHIND THE SINGLE PIN!
SO THE SINGLE PIN WILL HIT THE GROUND FIRST!
SIGH
SORRY GANG... A TIE SCORE
HOW COME ???
WHAP!
PLINK!
SINCE THE BAG HAS BOTH A GREATER WEIGHT AND A GREATER INERTIA, ONE OFFSETS THE OTHER!
$\left(\frac{\text{WEIGHT}}{\text{MASS}}\right)_{\text{BAG}} = \left(\frac{\text{WEIGHT}}{\text{MASS}}\right)_{\text{PIN}} = g$
THE ACCELERATION IS EQUAL FOR BOTH!
OF COURSE


SATELLITE PHYSICS
YOU SAY YOU DON'T UNDERSTAND WHY SATELLITES ORBIT --- WATCH THIS --- TELL ME WHAT YOU SEE WHEN I DROP THIS ROCK
IT FALLS STRAIGHT DOWN BECAUSE OF GRAVITY!
KERPLUNK!
CORRECT! NOW I'LL MOVE MY HAND SIDEWAYS WHEN I DROP IT --- WHAT DO YOU OBSERVE?
AHA! IT FALLS AGAIN --- ONLY THIS TIME IT FOLLOWS A CURVED PATH
KERPLUNK!
CORRECT! WHEN I DO IT AGAIN AND MOVE MY HAND EVEN FASTER WHEN I DROP IT, WHAT DO YOU OBSERVE?
!
KERPLUNK!
TWO THINGS: I OBSERVE IT FALLS FARTHER DOWN RANGE, AND IT TRACES A WIDER-CURVED PATH!
EXCELLENT! NOW WHERE WOULD IT LAND IF IT MOVES FAST ENOUGH SO THE CURVED PATH IT TRACES MATCHES THE CURVATURE OF THE EARTH?
PHYSICS! PHYSICS!
I GET IT! IT WILL STILL BE FALLING, BUT DUE TO THE MATCHING CURVE OF THE EARTH, IT WILL FALL AROUND THE EARTH RATHER THAN INTO IT. IT WILL BE AN EARTH SATELLITE!
... BUT IS IT REALLY THAT SIMPLE?
YES! THERE ARE VARIATIONS TO CONSIDER, BUT THE BASIC PHYSICS OF SATELLITE MOTION IS THAT SIMPLE SIGH
Hewitt Drew it!

Children's dynamics

ROGER OSBORNE

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Newtonian dynamics with its logical structures and teaching sequence would appear straightforward to learn, but somehow it is not. Even university physics students can have problems with some of the most basic ideas. Consider, for example, that 77% of a group of first year university physics students could cope with the relatively complex applied mathematics task of Question 1 of Table 1 but only 61% of the group could correctly answer Question 2. Why would Question 2, which involves very central and basic ideas necessary for even an elementary understanding of Newtonian dynamics, be so difficult for students who have studied physics for three years?

A closer analysis of Question 2 shows that 28% of the students (N = 120) chose an answer which included "the force of the hit" as one of the forces acting on the ball. Such a viewpoint, sometimes called impetus theory — that a moving object necessarily has a force in it in the direction of motion — is common amongst students of physics in many countries, including France,[1] Britain[2] and U.S.[3] Our own studies in New Zealand[4] show that impetus-like beliefs appear to actually increase in popularity during the junior high school years, and are very common amongst elementary school teachers. It is interesting to note that the impetus theory was held by some Greek and Medieval philosophers, including Galileo in his early writings, and the similarity of these beliefs over centuries suggest that they are a natural outcome of experience with terrestrial motion.[5]

There may exist a whole system of conceptions surrounding an impetus-like belief in the beginning physics student.[6] Certainly many of the ideas held by children and students about force and motion are interrelated and interdependent. However, as we shall discuss, they do not form anything like the logical structure of interconnected ideas found in a Newtonian formulation.

Children's ideas about force, and related topics such as friction[7] and gravity,[8] suggest that commonly held non-Newtonian conceptions include

A moving body has a force in it
The speed of a body is caused by the force
A stronger force will completely dominate a weaker force
All things fall down, but heavy things fall fastest
Friction is something which only occurs when things move
Friction increases with the speed of sliding
"Barriers" like table tops stop objects falling
Objects can resist sliding because they are stuck
The state of rest is fundamentally different from the state of motion
Gravity increases with height above the earth
If there is no air there is no gravity

The above ideas are also held by some adults and are certainly not unique to children. Nevertheless in terms of teaching and learning at the school level it is useful to collectively describe these notions as part of "children's dynamics." On the other hand, this is not meant to imply that the above ideas are held by all children or that any one child would hold them all. However, they are frequently heard when children talk about force and motion. Further, children make statements which follow as a direct consequence of these ideas. For example, if a child who thinks that "if there is no air there can be no gravity" is told that "there is no air on the moon" then it is not surprising that he or she might assume that "there is no gravity on the moon." This latter view is held by some 44% of 13 year old pupils in New Zealand.

Table 1

A comparison of two physics problems
(best answers (b) and (c) respectively)

1. The three forces (Ignore this one)

$\vec{F}_1 = 5\hat{i} + 4\hat{j}$
$\vec{F}_2 = -7\hat{i} + 2\hat{j}$
$\vec{F}_3 = 2\hat{i} - 2\hat{j}$

act concurrently at the point $3\hat{i} + 5\hat{j}$. The torque with respect to the point $2\hat{i} + 5\hat{j}$ is:

(a) $2\hat{i}$ Nm (b) $6\hat{k}$ Nm (c) $10\hat{j}$ Nm
(d) $12\hat{i}$ Nm (e) $15\hat{k}$ Nm

2. A golf ball is traveling through the air as shown.

A student states that there are three forces on the ball:
A the force of gravity
B the force of the hit
C the force of the air resistance

In fact the force on the ball is made up of:

(a) A only (b) A and B only (c) A and C only
(d) A, B, and C only (e) B and C only

Various studies have shown how difficult it is to change the ideas that children hold. Certainly, our own attempts to change school children's ideas about force and motion have yielded mixed success and even being aware of the intuitive ideas that university students hold has not enabled us to be entirely successful in our teaching, as we have exemplified earlier.

Mini-theories

How do children acquire "children's dynamics"? Certainly it would appear not to have been taught to them but rather through experience and the use of language they have generated their own theories as to how and why things behave as they do.[9]

It has been argued by Claxton[10] that through learning about the world, from the day we are born, we develop mini-theories which apply to specific situations and help us to make *predictions* and decide on certain *actions*. The theories may operate at a subconscious level of thinking; they need not be articulated, and can be used in a spontaneous and intuitive way. For example, a child requires a "theory" about projectile motion if he or she is to successfully catch a ball, but it may be a theory he or she would be quite unconscious of and unable to articulate. Mini-theories also enable individuals to offer *descriptions* and *provide explanations*. For these things to occur, the theories need to be framed consciously and articulated in the child's developing language.

Children are not too interested in coherence between theories and therefore mini-theories might be expected to have a limited range of applicability and be context dependent. "Gravity increases with height above the earth" and "there is no gravity in space" can be two mini-theories without conflict in a child's mind. In contrast physicists have become increasingly preoccupied about coherence between theories and this has led to complex and abstract conceptions which are far removed from simple explanations of everyday phenomena.

Children, like scientists, change mini-theories when it is expedient to do so. Claxton argues that either the theory itself is changed, which results in changes in predictions, actions, descriptions or explanations, or the set of situations, to which the theory is considered to apply, is changed. Such changes are likely to be caused by incorrect predictions or actions, or descriptions or explanations which are found not to be useful. On the other hand, theories are reinforced when they lead to predictions, actions, descriptions, and explanations considered appropriate and successful by the learner.

Clusters of mini-theories

We have so far distinguished between what we have called "children's dynamics" and "physicists' dynamics", a distinction between intuitive ideas formulated by the child and ideas based on our heritage and culture. However, it has been implied by Claxton that there may be two distinct clusters of mini-theories within "children's dynamics" which could be called "gut dynamics" and "lay dynamics." The three clusters — gut dynamics, lay dynamics, and physicists' dynamics — are distinguishable, although probably not entirely separable.

Gut dynamics. Einstein is reputed to have stated that even a physicist learns half his or her physics by the age of three. Much of this is dynamics, and it is largely "gut dynamics." Through trial and error this learning occurs in the home and is based on direct experience rather than language. The active efforts made at a young age to comprehend the world enable children to make predictions about what will happen, for example, to an object thrown from the high chair or kicked along the kitchen floor. Gut dynamics is about the tangible world and influences motor skills and perception. This perception can be quite different from the reality staring one in the face, e.g., the shape of the path of a projectile.

The collection of mini-theories constituting "gut dynamics" tend to be unarticulated and not necessarily conscious. Rather they are shown in a person's spontaneous reactions and intuitive judgments and tested against "does it work" and "is it useful." Gut dynamics provides the individual with the ability to interact physically with the world whether it be for work or pleasure. Sport is largely played using "gut dynamics."

Examples of gut dynamics for many people would include, heavy things fall fastest, things need a push to get them going, you have to keep pushing to keep things moving, rubbing causes things to heat up and wear out.

Language is very much second place to experience in terms of gut dynamics, but where it is involved it is the everyday spoken language of the community, e.g. "hit the ball closer to the top of the bat and it will not go so much."

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*The basis of an address to a Senior Physics Teachers' Conference, Hamilton, New Zealand, January, 1984.

Lay dynamics. Unlike gut dynamics which is based on direct experience, lay dynamics is based on the form and content of the language the child grows up to speak and the accounts and images of experiences conveyed by those with whom the child comes in contact, the media, and the authors of the books he or she reads. Claxton argues that these ideas may be accepted passively sight unseen and gradually, so that the child may grow up not even realizing that they are there. The wealth of visual and verbal information that the average child receives — for example from "Star Wars" and "Space Invaders" involving force fields and time warps, NASA pictures and "That's Incredible" involving weightless astronauts and feats of magic — provides him or her with a mixed up store of fact, fantasy, and belief related to dynamics. This store is quite extensive even before the child reaches school and may be held quite independently of "gut dynamics" and not related to it.

Examples of lay dynamics would be the idea that "astronauts are weightless in the space shuttle" (NASA pictures), "oil reduces friction and hence reduces wear" (TV advertisement), "space travel requires powerful engines at all times" (Star Wars), "the force of the explosion can be seen in the damage" (News), and "the force field kept him out" (science fiction story).

Lay dynamics provides an individual with knowledge that can be used to provide entertaining conversation. However, it is of little practical use in terms of doing things.

Physicists' dynamics. In the school setting physicists' dynamics is primarily Newtonian dynamics. It appears to many beginning physics students to apply to a strange world of frictionless slopes and pulleys, uniform gravitational fields and point masses, and rigid light rods and massless strings of uniform tension. Even in the laboratory air tracks, air tables and air pulleys imply an attempt to demonstrate some fantasy world set apart from reality.

While gut dynamics builds on experience and lay dynamics builds on everyday language, physicists' dynamics has a linguistic and mathematical superstructure of its own. Sometimes it is counter intuitive, for example, a car moving at a steady speed around a circular path is accelerating and this point is not open to question. The knowledge is articulated, consciously and deliberately transmitted and received, and, if understood, forms a highly coherent set of ideas. A variable amount of active and self directed experimentation is possible but the experiences often tend to show the limitations of the idealized theories rather than providing supporting evidence for their usefulness. Examples of physicists' dynamics to contrast with the gut and lay dynamics discussed earlier include: all freely falling things accelerate towards the earth at 9.8 ms^{-2}, an object moving at a steady speed has no net force acting on it, and the force of gravity acts on the astronaut in orbit accelerating him or her toward the center of the earth.

Integration of clusters

All individuals have at least two clusters of mini-theories, gut dynamics and lay dynamics. However, students of physics undoubtedly have three clusters of mini-theories, each derived from a different learning base. Do these students integrate their gut, lay, and physicists' dynamics into a coherent interrelated whole? Much of the research cited earlier suggests that many do not. Many reasons can be put forward for this:

1. Many students do not appreciate that the aim of elementary dynamics courses is to provide them with an alternative conceptualization to gut dynamics using a language different from the language of lay dynamics. Rather they simply assume that the teacher is trying to help them see connections between their gut and lay dynamics and to help them express their gut dynamics more effectively. One even suspects that some elementary school teachers are under this same misapprehension. The apparent increase in popularity of impetus-like ideas through junior high school may simply reflect that the pupils have become more fluent at expressing their gut dynamics.
2. Many pupils undoubtedly do develop a set of "physicists' dynamics" mini-theories which enable them to operate in the idealized world of the laboratory "experiment" and the physics examination paper. However, they often do not relate this aspect of "physicists' dynamics" to their gut and lay dynamics in any sensible way as they see no need to do this. Gut dynamics enables one to play ice hockey, lay dynamics enables one to talk about Star Wars, while physicists' dynamics enables one to do physics assignments. There is no problem!
3. To think through different aspects of gut, lay, and physicists' dynamics where they can be applied to the same situations so that a coherent and integrated view of dynamics is stored in memory can be a threat to one's ego (I might fail), to currently useful knowledge structures (it might ruin rather than help my game of ice hockey) or it may simply annoy friends and family (Mom doesn't understand if I talk like our physics teacher).

Perhaps, therefore, it is not so surprising that for many students their gut and lay dynamics are not developed through their physics courses in useful ways, nor are they related to what they are taught in the physics classroom.

Alternative aims for teaching dynamics

The previous discussion leads us to consider what should be our aims for the teaching of dynamics at the school level. Claxton implies we are faced with two incompatible alternatives:

1. To teach people "physicists' dynamics" as a new language and conceptualization without attempting to link it to gut and lay dynamics.
2. To help children develop their ability to make predictions, perform actions, describe and explain motion and the causes of that motion as it relates to their world.

?

In other words, is the aim of dynamics teaching to inculcate children into a new language and conceptualization without regard for their present ideas, or is it to help children make better sense of the world in which they currently find themselves? Is it to impose "physicists' dynamics" or to develop gut and lay dynamics toward a more coherent and useful viewpoint?

?

Let us consider each of these alternatives.

Teaching physicists' dynamics. Teaching physicists' dynamics involves a view that physicists' dynamics is "right" and any alternative viewpoint is simply "wrong" or at least a misconception. Such misconceptions are best ignored since the teaching aim is not to develop the accuracy, coherence, or effectiveness of the child's everyday encounters with nature, nor to develop his or her language in which experiences based on these encounters can be articulated. Rather the aim is simply to effect transmission of a body of knowledge isolated from, and independent of, prior experience and use of language. Indeed, relating the ideas being taught to everyday examples and analogies, and to the common use of language, may hinder rather than help, since it will "call up" unwanted aspects of gut and lay dynamics. Unfortunately, the problem with this approach is that children necessarily bring their gut and lay dynamics to the physics lesson. Children cannot absorb new meanings but can only construct ideas in their own heads on the basis of what they know already. A child's gut and lay dynamics are used to construct meanings, whether we like it or not, and so what is taught can often be misinterpreted in terms of these alternative conceptions. While limited school success can be gained by rote learning formulas, the lack of meaningful understanding can lead to an inability to apply the knowledge to the solving of even the simplest problems. That some university students continue to apply their uninfluenced gut dynamics, albeit dressed up in the language of lay and physicists' dynamics, to problems requiring physicists' dynamics, suggests that the "teaching physicists' dynamics" approach has been even less successful than we might have thought.

Developing real-world ideas about dynamics. The aim here is to help children better understand their present ideas, the relationship between those ideas, and how these ideas can be modified and developed to improve real-world prediction, action, description, and explanation. The idea is to help a child toward a coherent, integrated, and useful body of knowledge by accepting as a starting point the child's present ideas.

The problem with the "developing real world ideas" approach is that each child lives with his or her own mini-theory clusters of gut, lay, and physicists' dynamics and the individual exploring, challenging, and modifying of views is clearly impractical with large classes. In addition, most syllabuses and examinations are not designed with this aim of teaching dynamics in mind. Examination papers simply assess how much physicists' dynamics is known and most examiners are not concerned about the state of a child's gut and lay dynamics and whether or not they are coherently linked to physicists' dynamics. Perhaps in this regard Q. 2 of Table I may be considered an unfair question since it attempts to evaluate such linkages?

Which of the above two aims is adopted by teachers at present? Our experience of watching lessons on dynamics at the elementary school level suggests that the learning environment at that level is often a strange mixture of mainly gut dynamics from pupils, mainly lay dynamics from the teacher, and simplified physicists' dynamics from the curriculum developer (Fig. 1). Undoubtedly primary teachers would like to develop in children real-world ideas about dynamics but they are neither aware of children's present ideas or how they can best be developed. They receive little useful guidance in this. For example, activities frequently suggested involve children in rolling ball bearings across desks, or sliding blocks down planes. Such experiences are familiar to all children and completely interpretable in terms of children's gut dynamics.

As a consequence it is not surprising that children are left with a feeling that teachers are simply trying to help them relate a language to their gut dynamics.

At the junior secondary school level there is a wide range of teaching. However, it is usually based on the "teaching physicists' dynamics approach" and our evidence would suggest that this is largely unsuccessful for the reasons discussed earlier.

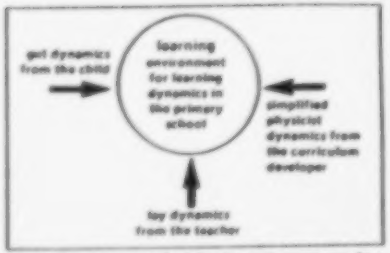
gut dynamics from the child
learning environment for learning dynamics in the primary school
simplified physicist dynamics from the curriculum developer
lay dynamics from the teacher

Fig. 1. The elementary school learning environment may be a strange mixture.

At the senior secondary school level "teaching physicists' dynamics" approach and "developing real world ideas about dynamics" should be compatible if early teaching has been appropriate. Unfortunately, students entering this level of education at present seem to have firmly established ideas based on gut and lay dynamics which are still quite different from and incompatible with ideas based on physicists' dynamics. If we, as teachers of senior physics, try even harder to encourage real understanding of physicists' dynamics, pupils can report that they are finding physics more rather than less difficult. To retreat into a world of applied mathematics, of recall and substitution problems involving algebraic and numerical manipulation provides a haven for pupils, teachers, and examiners in an otherwise frightening world of misunderstandings and misinterpretations. Further, it is a world which some of our best students seem happiest in, where they can excel in terms of present assessment mechanisms. We as teachers are caught in the middle of a conflict of desires as we want to do the best for our pupils both in the short and long term.

What should we do?

I would argue that the teaching of dynamics must begin at an early age. Without teaching, pupils develop their gut and lay dynamics in ways which are inflexible, limited and inappropriate for the overall best prediction, action, description, and explanation in the real world or for subsequent learning of "physicists' dynamics." To argue that the teaching of dynamics should begin early is not, however, to argue for the teaching of physicists' dynamics. Rather the teaching of dynamics from age 5 to say age 15 should help develop, challenge, and extend gut and lay dynamics in such ways that it helps make better sense of the world and in such ways that the formalized alternative conceptions provided in the senior high school will find a meaningful and valued place. What is required is a smorgasbord of experiences and debate which challenge and modify gut dynamics, as well as clarify language and the purpose of language and distinguish fact from fantasy in terms of lay dynamics. Moreover, the experiences and discussion should provide seeds of alternative conceptions upon which the later teaching of physicists' dynamics can be firmly based. Some possibilities are given in Table II.

This certainly does not mean the problems outlined

Table II
Suggestions for developing gut and lay dynamics in the junior school

Experiences to develop gut dynamics (activities and thinking)
- playing with an air track, air table, or other near frictionless surface
- playing with "the monkey and the hunter"
- measuring the changing speeds and/or paths of moving objects, e.g., projectiles with strobe photographs, cars rolling down slopes with timer
- feeling the force of 1 N, 10 N, 100 N
- watching and discussing things falling in an evacuated glass tube
- measuring the force required to slide various objects, with a spring balance
- observing distortions of the support as heavy objects are placed on beams and tables
- observing and drawing what happens when a whirling ball on the end of a string is let go
- measuring the centripetal pull on something to keep it moving in a circle, using a spring balance

Experiences to develop lay dynamics (language and discussion)
- isolating fact from fantasy (e.g., "overcoming inertia," "force barriers")
- learning words have different meanings in different contexts (e.g., force, weightlessness)
- learning to qualify words such as friction ("force of friction" from "heat due to friction")
- learning of differences between words (e.g., pressure from force, force from momentum, density from weight)
- countering folklore (e.g., people wear heavy boots on the moon since there is no gravity)
- countering images from science fiction (e.g., spacecraft move steadily through space with engines full on)
- distinguishing aspects of gravity (e.g., "speed of fall" from "pull of gravity")
- looking at cause and effect (e.g., existence of air doesn't produce gravity)
- learning we can define word meanings or allow usage to dictate, but for science definitions are necessary

are no concern of the teacher of the introductory physics. First, an appreciation of the existence and importance of gut and lay dynamics should influence what is taught even in college physics. Both for providing a firm foundation for future learning in physics, as well as for giving pupils an appreciation of the relevance of physics to their world, a sensitivity to physics students' ideas is important. Discussions in class on aspects of gut and lay dynamics and how they relate to, and can be different from, physicists' dynamics is, in my experience, time well spent even at the first year university level. To ask questions in physics examinations which explore how gut and lay dynamics have been developed by pupils and integrated with physicists' dynamics is of value both to pupils and society.

Second, teachers of junior science and primary pupils need all the support and guidance that they can get from the teachers of physics. Where the local teacher of physics is enthusiastic about "developing ideas in dynamics" at the junior levels, rather than proposing that "no dynamics" or "physicists' dynamics" be taught at those levels, physics will prosper. How can the teacher of physics help? Let me give two suggestions as examples from Table II.

Developing gut dynamics: an example. A teacher of physics who considers that dynamics should be taught only in the senior school and who sees no point in developing gut and lay dynamics is not likely to allow the air track to be used by junior classes. After all, not only might it get broken but the novelty is likely to have worn off by the time the pupils get to physics classes. On the other hand, a teacher of physics who acknowledges the importance of extending and challenging gut dynamics may well appreciate the value of providing even very young children with endless opportunities to play with an air track, air table, or other frictionless devices.

Developing lay dynamics: an example. It could well be argued that impetus-like theories arise in part because of a semantic problem. The concept of "*momentum*" is a central aspect of gut dynamics but it becomes incorrectly labeled as a *force* as a consequence of everyday language (lay dynamics). It can be argued that to develop gut and lay dynamics towards physicists' dynamics involves introducing the term *momentum* to children at a relatively young age and later distinguishing it from *force*. Net force changes momentum. These ideas form the basis of an approach to dynamics in the junior school which we have tried, and made available to junior high school teachers. However, again without the support and appreciation by the teacher of physics of what is being attempted, little innovation is likely to occur.

Conclusion

Let me propose three actionable projects for you as the teacher of physics in your school area for this year. The introduction of an air track into your local primary school or kindergarten, the consideration of "momentum" as a concept to be taught at the intermediate and/or junior secondary school level, and the inclusion in your senior physics examination of some questions to check on the development of gut and lay dynamics and how well they are integrated with physicists' dynamics. At least it will be a beginning.

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The fine-beam cathode-ray tube and the observant and enquiring student
Part 7

For a description of the experimental apparatus, see Part 1 on page 80 of the February issue

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Teacher and student have now nearly completed investigations into those otherwise unpublished uses of the F.B.C.R.T. and its Helmholtz coils which our student, with his necessarily limited knowledge in the relevant fields of theoretical and experimental physics, can profitably pursue. There remain three very interesting and didactically worth while lines of enquiry, of which two were followed in the activities described below, the third to be examined in a later, final session.

Teacher We have spent a good deal of time examining what I will call the dynamic properties of the beam — the electron stream made visible by the excitation of helium gas — in the presence of electromagnetic and electrostatic fields. Now I would like you to spend a little more time in examining the nature of the mantle, and in finding, if you can, the spectral content of the glow which lights up both beam and mantle.

Student O.K. I'll probably need a couple of lab sessions to work this out, and then I'll report back with a write-up, and begin asking *you* questions.

Later: The student's write-up

(1) *Properties of the mantle*

(a) I began investigations with the Helmholtz coils still having their magnetic axis along the transverse beam line, but with no coil current flowing. On turning up the anode voltage I noticed that the green glow volume surrounding the "spike" always had a definite, characteristic, and beautiful geometric form, widest at its base and tapering, in the manner of a cone, to a tip, but with a leaf-form rather than triangular axial section. It is possible to propagate this restricted beam a little beyond the spike tip, but the colour of this extension differs from the general glow by being pinkish, suggestive of the colour of an excited helium spectral tube, and the beam spreads out. The mantle does not extend beyond the tip of the spike in these circumstances (Fig. 1).

I deduce that, up to the primary focus point in this restricted beam, there is a sufficient but gradually diminishing supply of electrons having enough energy to produce the necessary helium atom ionisation. It is the random scattering of energetic electrons from the main beam path, by both elastic and inelastic collisions with helium atoms that is, at least in part, I believe, responsible for the visible mantle. It is the consequent and inevitable gradual decrease in the intensity of this scattered electron shower with its progress along the beam that determines the geometric form of this mantle. But I also believe that a large proportion of the mantle's glow arises from the "handing on," outwards, from helium atom to helium atom, of the spectral components of the primary glow of the beam itself.

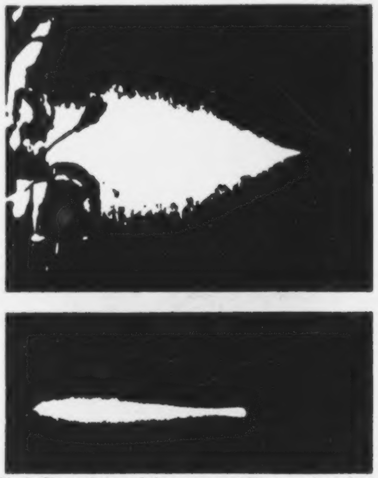

Fig. 1. (Upper photograph, long exposure.) The green glow volume surrounding the "spike" always has a definite, characteristic, and beautiful geometric form.
(Lower photograph, short exposure.) It is possible to drive the restricted beam a little beyond the spike tip, but the colour of the extension becomes pinkish, rather like the helium spectral tube colour.

Beyond the focus point (the only focus point in this restricted beam case) the surviving electrons which remain in the beam path have insufficient energy to ionise helium atoms, and ultimately, at the end of this limited visible path, to excite atoms at all. In this short beyond-focus pink-coloured beam, the range of remaining electron energies permits excitation of the helium atoms to a variety of levels, with consequent emission of familiar helium spec-

Physical science workshop course for elementary teachers

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(Received 30 June 1980; accepted for publication 19 March 1981)

(The Conclusions Section has several ideas for topics)

INTRODUCTION

Science for elementary school grades K–6 varies somewhat in content from one textbook series to another, but it is fairly common that 40–60% of the material covered is directly related to physics. These texts suggest that certain learning activities such as experiments, demonstrations, and observations be carried out by the teacher and the class. Often the apparatus for a learning activity is to be constructed from simple, readily available materials. The typical elementary school teacher has had little experience in performing experiments and is often frustrated in his/her attempts at carrying out the suggested learning activity. To meet this need we have developed a physical science workshop that is made available to teachers who are returning to the university for additional training.

This course is based upon the assumptions that most elementary teachers have had little or no physics and lack the competence and confidence to carry out an activity-oriented science program; that most experiments should be carried out using readily available and easily constructed materials; that skill in using hand tools is needed by most teachers; and that teachers who learn in an activity-oriented course are better prepared to teach in that mode.

FORMAT

The class is conducted in an informal workshop format in which each student works on her (since most participants are females, we choose to use the feminine gender) own apparatus and does the experiments individually. The lab partner arrangement is not used since that tends to produce one "doer" and one "watcher." The course requires a total of 60 hours of participation, and participants may recieve up to four semester hours of credit toward a master's degree in education. The energy output of the instructor is very high, and the number of students per instructor should be limited to about twelve; although, we have successfully team taught sections as large as fifty by using four instructors. The instructor conducts demonstration experiments, pre-lab and post-lab explanations, and is otherwise constantly involved in explaining concepts to individual participants. The experiments can be divided into three types: (1) directed experiments, brief in duration, during which the instructor explains the results observed and helps the students understand what is observed (much of Unit I is of this type); (2) experiments carried out by the students and discussed in a post-lab session (Units II, V, and VI contain the best examples of these experiments); and (3) observation of phenomena utilizing easily contructed or readily available materials where data are not taken but the phenomenon is observed and described (Sec. III is the purest example of this type). Some of the sections mix all three approaches.

The course has been taught in several different time arrangements including one evening per week for an entire semester, two evenings per week for eight weeks during a regular semester, as a six-week summer course and as a three-week summer course. Each arrangement has some advantages and disadvantages. The first two have the advantages that the participant can put the material to immediate use in her classroom and have the instant reward of seeing the children's responses. One disadvantage is that both the participants and the instructor are tired after having worked all day, and this fatigue tends to limit enthusiasm. A second disadvantage is that all materials must be brought in and removed from the classroom for each class meeting.

The two summer programs lose the above advantages but more than make up for them by eliminating the disadvantages listed. Our experience indicates that the three-week course meeting 4–6 hours per day for ten to fifteen days in a room used for nothing else offers the best teaching situation.

The course has been taught in school cafeterias, libraries, elementary school classrooms, high school science laboratories, and university laboratories. We think it is best taught in an elementary school classroom since the participants overcome the same space and facility difficulties during the course as they will face in implementing a physical science program in their classes. Most importantly the course must be taught in a free and easy workshop atmosphere where students can learn from each other, get immediate answers to their questions and learn that doing science experiments can be an enjoyable experience.

Hand tools, lightweight electric drills, and saber saws are provided along with most materials needed to construct each piece of experimental apparatus. Each student builds apparatus with which she does experiments, and when the course is finished, she takes the apparatus she has built. Other experiments make use of commonly available materials, such as spectacle lenses, aquarium, and musical toys. When the course is finished each participant has enough materials to carry out nearly all of the experiments and demonstrations. Special apparatuses, which are either expensive or difficult to obtain, are avoided.

Every aspect of the program is part of a planned effort to give the participant confidence and competence to carry out an activity-oriented physical science program in her school.

CONTENT

It was our goal for each participant to gain a measure of competence in performing approximately 100 experiments and demonstrations from the various areas of physics. For example, in Unit I the student makes an alcohol burner from a baby food jar and clothesline rope and fuels it with spirit duplicator alcohol. The participants use the burner as the heat source for eleven experiments and demonstrations that can be done with test tube stoppers, glass tubing, and rubber hose. These experiments include boiling at low pressure, distillation of wood, distillation of liquids, and recrystallization of salt. Nine additional heat experiments are done in a later unit.

In the second unit an equal-arm balance sensitive to

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about 20 mg is constructed, and it is then used to carry out thirteen experiments including determination of the density of solids, liquids, and gases and a study of Archimedes's principle.

The optics unit contains 22 demonstrations and experiments using such items as mirror stock, pinhole cameras, aquarium, lenses, and shaving mirrors. Eleven experiments are included on weather, 16 on mechanics, 11 on sound, and 10 on electricity. A complete listing of the table of contents from our study guide is available on request from the author.

CONCLUSIONS

More than 200 persons have taken this course during the past six years, and student evaluations have been taken from approximately 100 of these. The course has been constantly rated as one of the best in which they have participated with respect to amount learned, potential for impact on teaching, and personal satisfaction with accomplishments. Follow-up interviews with teachers, science supervisors, and principals as well as unsolicited correspondence indicate that many who have taken the course have incorporated much of it into their science teaching.

Our experience indicates that physics departments can have an impact on public elementary school science teaching by developing and teaching courses that train the participant to conduct class experiments, develop apparatus, and perform the demonstrations that we have traditionally used in teaching elementary physics. However, the experiments need to be simplified and worked out so they can be done with readily available and easily constructed materials.

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The Physics of Fun

ROB Schuller may be the world's youngest physics teacher. Each weekend the Houston Museum of Natural Science pays this 12-year-old to play with toys. He shows visitors—especially the smaller variety—how to discover science while having fun. Rob's toys have mass, velocity, inertia, momentum, and weight. His toys "feel" gravitational and centripetal forces. They accelerate and decelerate. Through toys, Rob uses familiar experiences to draw children willingly into the realm of physics.

Rob begins his show with the simplest of toys—the ball. He drops a light ball and a heavy ball from the same height at the same time. The result often surprises his audience, and Rob asks the children to "help" him explain what happened. He guides them along by asking if it is harder to pull a loaded cart or an empty one. Together, they determine that the heavy ball receives more gravitational pull, which it needs to fall at the same rate as the light ball. Rob then shows his expertise at tossing a ball straight up and catching it. He asks where the ball will fall if he repeats his toss while walking. Most of the younger viewers expect the ball to drop behind him. Another surprise: the ball shares Rob's momentum and returns to his hand.

Next, Rob rolls a piece of clay into a ball and drops it. Splat! But he says momentum can make the clay ball bounce six feet high. The trick is to stick the clay ball on top of a bigger, bouncier ball. He drops both balls, which his viewers know will fall at the same rate and arrive together. The big ball receives an upward push from the floor and starts to climb. The clay ball on top captures the bigger ball's momentum and flies upward. Rob then drops the clay ball into a jar of water: it sinks with a splash. He asks for help in making the ball float. But curious viewers must wait until the end of the program to see how dense clay can be made buoyant—with the aid of physics. The trick, of course, is to shape the clay into a boat.

The momentum story continues with Rob's favorite toy, the water rocket. He first fills the smal rocket with air under pressure. When the air is released, its downward momentum shoots the rocke upward in a classic example of action and reaction

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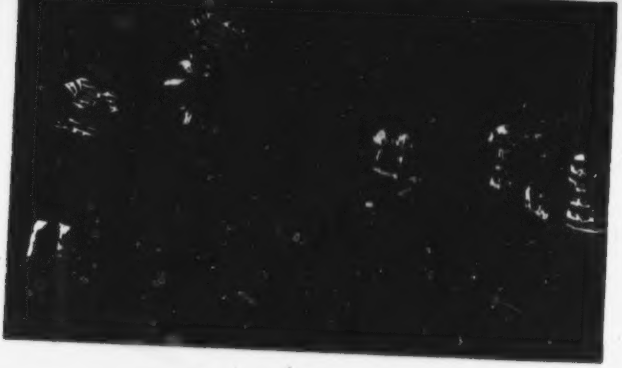
BY CAROLYN SUMNERS

Whether they're hanging upside-down on a roller coaster or monitoring marble momentum in the classroom, kids readily enter the realm of science through toys and amusement parks.



Flipping toys feature fascinating physics, and amusement park rides allow kids to truly get inside science concepts.

PHOTOGRAPHS: GARY YOUNG

Inductive physics, learned from enjoyable experiences and memories, makes sense to kids.

Rob then asks his rocket fans to predict what will happen when he adds water to the compressed air. Taking careful aim—remembering where the water will go—Rob fires the rocket. The water adds mass and therefore momentum to the escaping air and the rocket soars even higher.

The World as Laboratory

Rob's Science in Toyland demonstration grew out of the museum's Informal Science Study, funded through the University of Houston by the National Science Foundation. My colleagues and I at the museum are developing educational materials and classroom programs that draw on children's familiar and enjoyable experiences to teach the language and concepts of physics. Inductive physics—that learned from memories of toys, amusement parks, sports, and playgrounds—makes sense to kids.

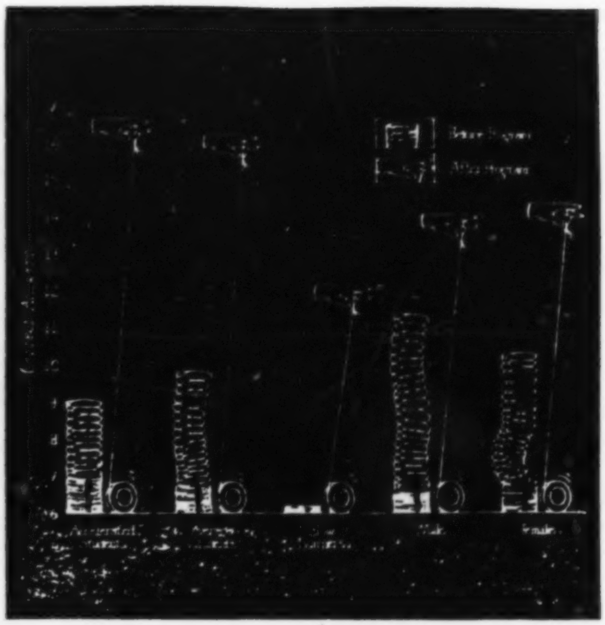
A sixth-grade girl inspired the study. I was trying to explain to her the "location" of the floor of a hypothetical space colony and why she wouldn't fall inward. But all my efforts, including swinging a bucket of water over my head, only caused more confusion. Finally, a sympathetic classmate told her to think about the rapidly spinning Barrel of Fun at the local amusement park. I will never forget the look of understanding on her face—she now had an experience to learn from. She could "feel" the centripetal force pushing inward from the sides of the barrel as its bottom dropped away, providing a structure upon which she could build abstract concepts.

We aimed first at developing materials and curricula for the middle grades—roughly five through nine—since this is the period when kids too often decide to "tune out" science. For them, science must become so interesting and meaningful that it is worth remembering and pursuing. We found that even students who had never made a contribution in science class could describe the feeling of zero gravity while rushing down a roller coaster hill and the 4-g valley that follows.

We've since developed programs for students in all grades, including accelerated students. Older students not only tackle more difficult scientific concepts; they also get into matters of engineering. They can probe the mechanical details of how toys work, or they might analyze blueprints and accelerometer readouts from roller coaster rides. We even challenge them to design their own toys and rides as an exercise in applying theoretical concepts.

We've now tested our programs on more than 5,000 students from around the country. In St. Louis, for example, 12 ninth-grade classes spent a month working with our materials—experimenting with toys, studying amusement park rides, and topping it off with a trip to the Six Flags Over Mid-America park. We tested them before and after the program, measuring their knowledge in three areas: comprehension of mechanics concepts; recall of science experiences; and ability to apply mechanics concepts to new situations. Students of all academic abilities showed significant learning gains in each category *(see chart, opposite page)*, with slow learners recording the same percentage gains as accelerated students. Girls, who began with lower scores, reached or exceeded boys' scores. This came as something of a surprise; from sports to machines, most mechanics experiences have a definite "male" bias. But we found that the girls had ridden more amusement park rides more often, a fact that gave them a relevant "knowledge base" for learning about physics.

Fueled by such successes, the materials and curricula developed in the Informal Science Study will soon be "going national." The Department of Education (DOE) has reviewed the programs and will include them in its National Diffusion Network—a list of educational programs that the department deems effective. The list is sent to school districts nationwide, and schools interested in our programs can contact us. We will provide materials and conduct workshops for teachers on a shared-cost basis using DOE funds soon to be appropriated.



Teaching science through fun works. Ninth graders tested before and after experimenting with toys and rides chalked up major learning gains. This graph charts scores for comprehension of mechanics concepts, often difficult to teach.

Opposite page: A toy scientist uses a yo-yo meter to "see" forces on a roller coaster. Left: Slinkies are great for gravity races. The stretched-out slinky won. Why? Because the center of its mass was lower to begin with.

Yo-Yo Meters and G-Force Detectors

Now let's take a trip to an amusement park with Amy O'Neal and Elizabeth Gregory. Amy, age 12, and Elizabeth, age 11, became "computer physicists" this summer in a week-long course we ran at the museum. They began by running computer programs we've developed that simulate many thrill rides. The girls designed loop coasters and watched riders stick tight even when upside down. They tilted curves so banking angles would hold riders squarely on their seats. They played arcade-style basketball with properly angled parabolic arcs. They gave just enough spin to a gravity-defying barrel so passengers would cling to the walls. They made changes that could never be made in a real park, creating dangerous rides without risking a rider's life and limb. In all, Amy and Elizabeth began to see the physical principles behind these familiar rides.

The girls then joined about 300 other computer physicists on a laboratory trip to Astroworld. They went equipped with scientific instruments and measuring devices picked up at a toy store. Elizabeth became an expert with the yo-yo meter, which she used to "watch" the forces she experienced on the rides. For example, on a suspended roller coaster called XLR-8, Elizabeth watched the yo-yo swing outward at each banked turn. The force of her body pushing against the seat confirmed the yo-yo's reading—the centripetal force produced by the banked curve exactly matched gravity's tug. The yo-yo proved that she would not fall off or fly away on this ride. On the scrambler, Elizabeth's yo-yo became a pendulum swinging back and forth. As she moved through the ride's complex spirograph pattern, her pendulum yo-yo faithfully maintained its swing, tracing each path in reverse as viewed by her moving eye.

But her most dramatic moment came on the loop coaster. Initially holding the yo-yo in her hand, with the string tied to her wrist for safety, Elizabeth released it when she was upside-down at the top of the loop. The yo-yo seemed to fall "up" rather than dropping to the ground. As she had learned in class, she was traveling so fast that the yo-yo, sharing her momentum, kept going in a straight line. She, however, was curving downward in the loop, so the yo-yo ended up in her lap.

Amy favored the paddle ball—a ball attached to a paddle by an elastic string—and turned it into a g-force detector to measure acceleration. Astronauts during lift-off may pull 3 g's, experiencing three times their normal weight, while in the weightlessness of orbit they experience zero g. To calibrate her g-force detector, Amy held the paddle upright and marked the spot where the ball rested normally—representing 1 g. She added a second ball to the string, which caused the elastic to stretch as far as it would with one ball under 2 g's of force, and marked this spot. She then repeated the process with a third ball to mark 3 g's.

DIAGRAMS: ELIZABETH SLOTE

For many students, science must become so interesting and meaningful that it is worth remembering.

On the roller coaster, Amy's detector showed the reduced g force of each drop and the extra g's encountered in every valley. Then she went on the Sky Screamer, which drops passengers from a 10-story tower. Amy plummeted for two seconds of free-fall followed by a landing curve that braked her descent. First the paddle ball floated freely in front of her—a certain indication of her weightless condition. As she entered the landing curve, the ball reached a reading well over 3 g's. She can carry this experience with her as a real-life example of physics in action.

Several parks around the nation are now using the materials, including physics workbooks, that we've developed. For example, the Six Flags park at Magic Mountain in California and Great Adventure in New Jersey run special physics "field lab" days, and the Six Flags Over Texas park is planning a similar program for physics and physical-science students. The Iowa Junior Academy of Science is testing a physical science laboratory at Adventureland in Des Moines using all of the eighth graders in the city's public schools. Both teachers and students are enjoying the attention. For years schools have rewarded the band, glee club, and sports teams with trips. It is encouraging to see a similar privilege given to science students.

Toys in the Classroom

For the past 3 years I have presented workshops at teachers conventions around the country. The workshops emphasize how to bring student experiences into the classroom—from science show-and-tell activities in the lower grades to toy activities and amusement-park laboratories for older students. In Houston, I've watched toy labs grow in several elementary and middle schools, where children seem to thrive when studying the world in miniature.

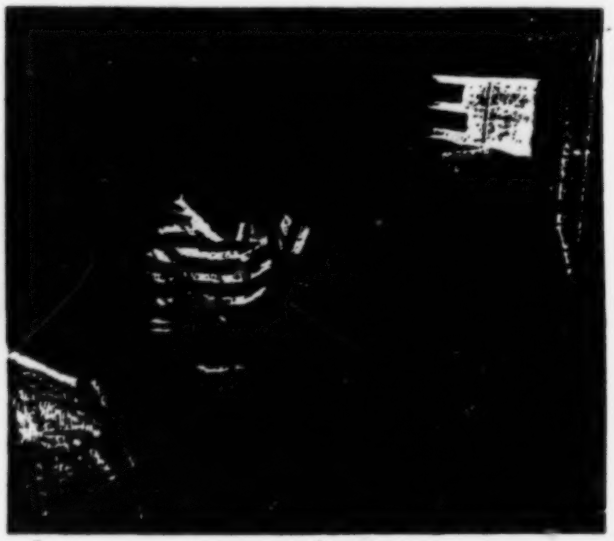
Some toys mimic human behavior—flipping, swimming, hopping, rolling, jumping, waddling, and walking. Whether they wind up, roll down, rev up from being pushed, or use batteries, these toys all have a power source somewhere. Describing the energy flow in the mechanical devices offers a simple introduction to the principle of energy conservation.

Toys that roll are meant to be raced, of course. Proper lab equipment includes a long downhill ramp of plastic or plywood that slopes gently to a hard floor straightaway. Some racers inevitably roll faster for very scientific reasons. Students discover that wheel friction is a killer, but several of the pint-size experts in this field testify that applying graphite works wonders. Crooked wheels waste too much of the precious gravitational energy. Wheel quality almost always takes precedence over wheel size. Aerodynamic styling can help if the race is close. Students who know that all objects fall at the same rate are often puzzled about what happens when mass is added to racers. Using clay and trial-and-error tactics, they soon learn that mass makes little difference on the downhill roll, but the extra momentum carried onto the straightaway makes heavier racers better every time.

After one great race, a female contestant requested that we use dolls in a demonstration. But that pointed to something that had been bothering us: dolls—traditionally "girls' toys"—don't lend the

Amy O'Neal and Elizabeth Gregory of Houston became computer physicists this summer. They tackled a breathtaking free-fall ride via computer, manipulating the ride's mechanical properties (right). Amy finally put theory to the test at Astroworld, where the freefall dropped her 10 stories (far left).

Amy measured her descent with a paddle-ball "g-force" detector. Floating before her face, the ball testified to her weightlessness (left). The detector measured more than 3 g's during braking, similar to the force on an astronaut at lift-off.



selves easily to science. Staring at a doll and wondering "where's the physics" only leads to frustration. Dropping or throwing dolls in the name of science surely provides little encouragement for budding female scientists. Finally, we hit on the idea of safety.

Roller skates that clamp over shoes make excellent cars for carrying dolls. The students would crash the cars and study the results, adding safety features for the next crash. Doll-sized seat belts, shoulder harnesses, head rests, and padded dashboards grew from classroom supplies. Class interest ran high: the girls cheered when the dolls survived, and the boys rooted for the wreck.

Another class modified this idea, replacing the dolls with raw eggs. Each egg had a painted face that had to remain visible during its ride. A ramp running abruptly into a wall guaranteed equally forceful crashes for all participants. Losers cleaned up the mess. As an interesting safety note, the sole surviving egg was protected by an air-bag system made from a balloon.

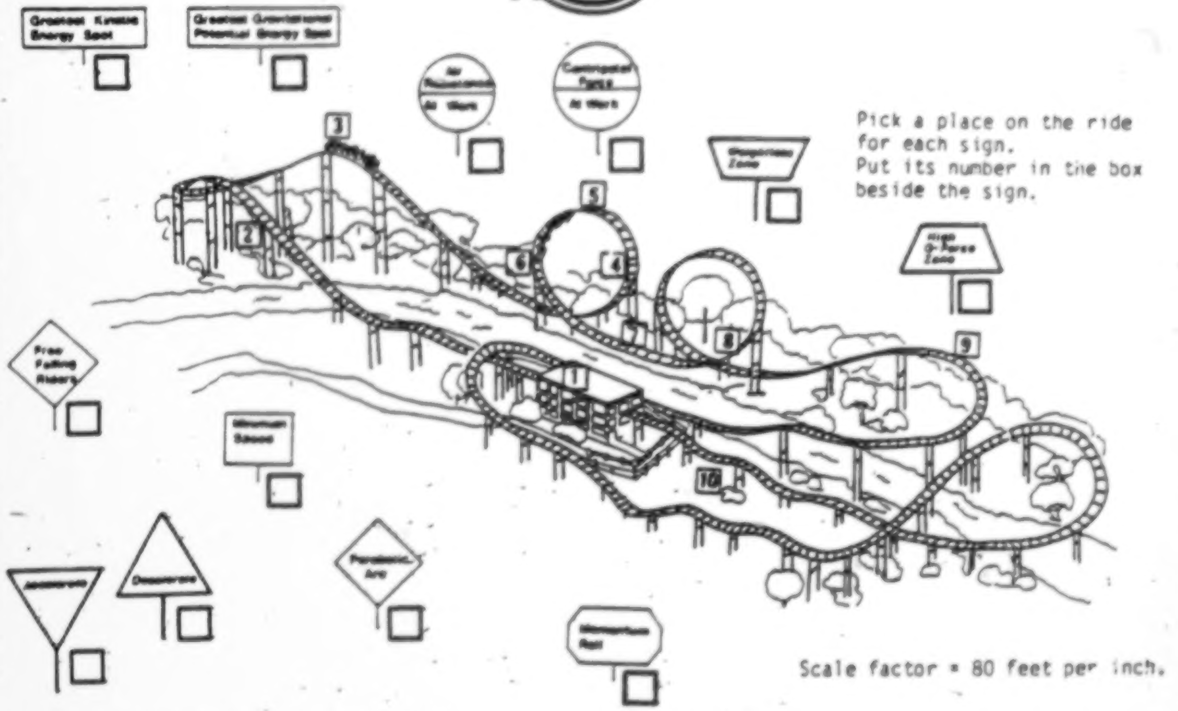
Flipping toys also make fascinating physics. With a push from its long curled tail, a toy cat can roll over. Tiny legs flip out and push toy cars and planes upside down and over. With a spring-loaded kick, a toy mouse flips high in the air and lands on its feet. A simple description of these forces and their directions is a lesson in Newtonian mechanics. Adding clay weights shows the delicate balance of each toy acrobat.

Marbles make excellent lab equipment. A ruler with a center trough along its length quantifies the marble player's art. Marbles of different sizes and speeds can be rolled along the trough into each other with great head-on accuracy. Students can see momentum passed from marble to marble in each collision. Students who do not speak algebra can still see that mass and velocity are both important in marble mechanics. A small marble must travel twice as fast as a marble with twice as much mass to stop it. And for observers, clear marbles make handy convex lenses that provide upside-down views of the world.

The slinky has long served teachers as a medium for demonstrating longitudinal (soundlike) waves and transverse (lightlike) waves. But we've also solved one of the greatest problems with slinkies: what to do wh[illegible] slinky is stretched or bent. Damage usually st[illegible] at the middle, rendering the toy useless. Such a slinky can be cut in half. The halves can then be dropped from the same height, with one

DISCOVERY ACTIVITY

LOOP COASTER


Greatest Kinetic Energy Spot
Greatest Gravitational Potential Energy Spot
Air Resistance At Work
Centripetal Force At Work
High G-Force Zone
Free Falling Riders
Minimum Speed
Parabolic Arc
1
2
3
4
5
6
7
8
9
10

Pick a place on the ride for each sign.
Put its number in the box beside the sign.

Scale factor = 80 feet per inch.

Hoight of first hill	- 116 ft	Weight of coaster	- 378.5 tons (approx)
Angle of first drop	- 36°	Length of train	- 49 ft
Height of each loop	- 70 ft	Chain speed	- 354 fpm
Maximum g-force	- 5.9 g	Frontal area of train (intersecting the wind)	- 3.7 ft x 2.8 ft
Minimum g-force	- 2.0 g	Horsepower of chain motor	- 200 hp
Speed limit	- 50 mph	Round trip time	- 111 sec
Minimum speed	- 3 mph	Round trip distance	- 1942 ft
Minimum rider height	- 4 ft		
Ride capacity	- 28		

half compressed and the other outstretched. In seeming defiance of the "all-fall-together" law, the stretched-out slinky hits the floor first. Students finally realize that it is the centers of mass that must be at the same height to make a gravity race fair.

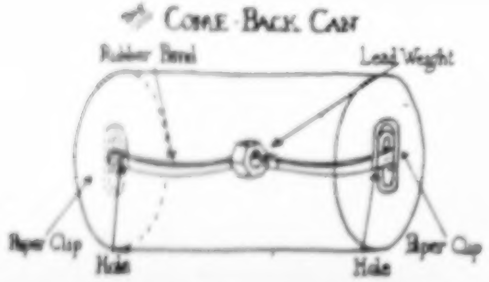
A car track with a ramp that hurls the car around a loop always proves a favorite. By adjusting the height of the ramp, students can change the car's speed in the loop. When the speed drops too low, gravity conquers inertia and the car comes tumbling off. Older toy scientists can calculate the exact height for the car's ramp in terms of the loop's diameter that gives the slowest acceptable ride. This demonstration gives students the opportunity to experiment with a model of an amusement park ride before experiencing the real thing. From watching the car, students develop an idea of what it would feel like to be inside. Going on the ride lets the learner slip inside his or her experiment to get a different perspective on the forces involved.

Students also enjoy speculating about which toys will work well in the zero-g conditions of the space shuttle. Could an astronaut yo-yo? Would a floating slinky still carry waves? Would a paddle ball be as easy to hit? Could a windup car run around the sides of a circular doorway without ever needing to be rewound? These fascinating questions have led me into negotiations with officials at NASA's Johnson Space Center in Houston. I've proposed that shuttle astronauts test some of these toys and videotape their efforts. The latest word is that this may happen during one of next year's missions. The videotapes would then be available to teachers.

Many Happy Returns

With the holiday season fast approaching, toys are on many people's minds. Anyone venturing into a

Several amusement parks across the nation now use materials developed in the Informal Science Study. This workbook problem asks students to mark where they experience various forces on a roller coaster (left).



Rob Schuller's Science in Toyland program delights children at Houston's Museum of Natural History. For example, doll-carrying roller skates provide a dramatic look at momentum in action (left). As a holiday science gift, Rob recommends the Come Back Can (above; see article for instructions).

toy store will find physics on every shelf—even though only one aisle will likely be labeled "educational." These toys, such as chemistry sets or microscopes, take a science-inclined child into the world of adult scientists. But there is as much applied science and engineering in those other toys that *all* kids want. Since many people automatically make a distinction between "fun" and "learning," the potential of these toys is often overlooked.

For those who forgo the toy store adventure, the staff of the Houston Museum of Natural Science recommends a special old-fashioned science toy. It is appropriately called the Come Back Can. Rob Schuller makes this toy from a soft-drink can, a rubber band, a one-ounce fishing sinker, and several large paper clips. He uses a nail to make a hole in the bottom of the can. He slips the rubber band through the sinker and knots it in the middle. He then feeds one end of the rubber band through the tab slot in the can top and secures it with a paper clip. With a hook fashioned from a paper clip, he pulls the rubber band through the hole in the can bottom and attaches it with another paper clip. The sinker must hang with a little slack, but should not touch the walls. The paper clips must be taped securely to the ends of the can, which may be decorated with smooth wrapping paper to add a festive touch.

Rob rolls his finished Come Back Can forward a few times to wind up the rubber band. Then he rolls the can across his stage. The can finally comes to a stop and begins to roll back. Toy scientists of all ages will be fascinated by this holiday treat while seeing an important scientific principle, conservation of energy, at work—or, rather, at play.

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